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A Cost Model of Deep Ocean Mining and Associated Regulatory Issues

MIT Sea Grant Program

Massachusetts Institute of Technology
Cambridge
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PREFACE

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None of those to whom we are indebted, though, share in the responsibility for the errors or opinions that may be expressed in the study. As indicated earlier, that is ours alone to share.

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Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

A. Nature and Use of the Study. This study constructs cost estimates for a deep seabed mining operation, simulates the projected cash flows, and calculates the economic return to the investor. By changing the assumptions and values used in the model, comparisons can be made of the impact of different policy and regulatory options on the profitability of the project.

A fairly detailed estimate is made of the capital costs of a single hypothetical first generation ocean mining project located in the eastern central Pacific. The costs are for the major components of a five-phase mining operation cycle: prospecting, exploration, mining, transportation and processing. Operating costs are similarly estimated and aggregated. There the major components are: energy, labor, materials, fixed and miscellaneous costs. The study makes reasoned assumptions as to these characteristics for a mining operation handling three million tons of nodules a year over a 25 year commercial recovery period.

The aggregated cost estimates are provided as input for the financial analysis section of the model, the initial function of which is the generation of cash flow projections over the life of the project. The cash flow data form the basis for making analyses to estimate the investment returns on the operation, and for projecting the values of the annual federal, state and local tax revenues accumulated over the life of the project.

Over 75% of the cost estimates of equipment components have been developed independently of the major industry consortia. However, an industry-government-university workshop was convened in March 1977, to review the model and the first draft of the study. Many helpful suggestions were received and incorporated into the subsequent version of the model and accompanying draft, which also had the benefit of being reviewed by the workshop participants.

Current international and domestic legislative negotiations raise myriad policy options for the U.S. government. Most will affect the economic return to be realized from deep ocean mining and therefore the commitment of those who currently have the technological and financial resources to invest in the industry. This study provides a ready means for comparing the impact of many of the options. The model is a tool for comparison. It is not a basis for a potential investor's decision on deep ocean mining.

The model provides insight into three kinds of policy or regulatory questions.

First, a great many technical and financial determinants of the economic viability of deep ocean mining are necessarily subject to uncertainty and variation. This study permits most determinants to be changed by the program operator. Varying these estimates can provide insight into the range of technical and financial options available to the ocean miner.

The second type of questions are those concerning domestic legislation issues such as political risk coverage, comparative costs to industry for requirements of U.S. vessels, crews and processing plants, effects of different tax treatments, contribution to national income, and so on.

Third, assuming LOS negotiations will include some number of projects operated by entities other than the proposed international seabed authority or enterprise, there are numerous issues which will have impact on a mining venture's return. Among them are royalties to be paid either to the authority or to the U.S. government in anticipation of an authority; exploration costs involved in the "banking" scheme; costs of training and technology transfer requirements; duration of "right to mine" agreements; production limits; splitting of the mining cycle into sub-cycles to be performed by different contractors; and, the time lags concomitant with the coming into force of any international agreement.

The premise of this study is that the public decision-makers involved in these issues will be beneficially informed by having available to them estimates of the financial or economic valuation of segments of the private and national interest which are based on detailed considerations of cost.

To avoid misuse of the model, the authors state the underlying assumptions for independent program variables and frequently define explicit bounds for them at the end of appropriate sections of appendices.

B. Cost Estimation Results. In the "baseline" model, costs are grouped into four types: research and development, prospecting and exploration, capital, and operating expenses. The values assigned to the input variables are identified in Chapter IV. The following table summarizes the four types of costs estimated for the "baseline" model:

Table ES-1

Summary of Cost Estimates
(in millions of dollars)

Research & Development	50.00
Prospecting & Exploration	16.40
Capital Investment	493.05
Total Capital & Operating Expenses Prior to Commencing Commercial Recovery	559.45
Annual Operating Expenses	100.5

1. Expenses Prior to Commencing Commercial Recovery. Prospecting and exploration costs of $16.4 million are composed of four expenses: prospecting cost, exploration labor costs for the research team, the cost of conducting the mapping survey, and the cost of conducting the survey for discrete

samples of nodules and soil. These prospecting and exploration costs are allocated over time and used as an input to computation of annual cash flow.

2. Capital Investment. Total capital investment in the ocean mining project of $493 million is divided into costs allocated to three major sectors of the cost model: mining, transportation, and processing. The division of the capital investment among the sectors and sub-sectors of the ocean mining project is illustrated in Figure ES-2.

Table ES-2

Allocation of Capital Costs: $493 Million
(in millions of dollars)

Mining Sector		Transport Sector		Processing Sector	
Platform	54	Sector Costs	55	Equipment	199
Pipe Handling	21			Utilities	84
Lift	9			Site	20
Power Plant	7			Buildings	20
Navigations	5			Waste Disposal	19
	96		55		342
TOTAL CAPITAL COSTS					493

3. Operating Expenses. Estimated annual operating costs for the ocean mining project of $100.5 million are also allocated among the mining, transportation and processing sectors. The costs of each sector are further divided into the annual expenses for energy, labor, materials, fixed charges, and miscellaneous items. These costs are shown in Table ES-3.

Table ES-3

Estimated Annual Operating Costs of the Baseline Model
(in millions of dollars)

Mining Sector		Transport Sector		Processing Sector	
Energy	3.7	Energy	3.1	Energy	19.3
Labor	4.0	Labor	7.5	Labor	23.8
Materials .	9.4	Materials ...	2.2	Materials ...	12.8
Fixed	3.0	Fixed	1.4	Fixed	6.8
Misc.	1.1	Misc.	0.7	Misc.	1.9
	21.1		14.9		64.5

TOTAL ANNUAL OPERATING COST 100.5

C. Results of Economic Return Analysis. The project goes into commercial production in its sixth year. Its annual production and revenues from then through the thirtieth year are as follows:

Table ES-4

Annual Production and Revenue

	Annual Production (lbs. x 10^6)	Revenue ($ x 10^6)
Nickel	85.5	171.0
Copper	74.1	52.61
Cobalt	8.64	34.56
Manganese	0.	0.
TOTAL ANNUAL REVENUE ...		258.17

The project does not report a loss for any year of commercial production. Annual cash flow turns positive in the first year of production and remains so for the life of the project.

Three measures of economic return are routinely provided in this report: Net Present Value (NPV), Internal Rate of Return (IROR), and Payback Period.

The NPV for different discount rates applied to the baseline case is shown in Table ES-5:

— — —

Table ES-5: Net Present Values for
Baseline Case at Different Discount Rates
(NPV in millions of dollars)

Discount Rate	8%	10%	12%	14%	16%	18%	20%	22%	24%
NPV	349.1	230	144.6	82.4	36.4	2.1	-23.9	-43.6	-58.7

— — —

The IROR for the baseline project is 18.14%. The Payback Period is 5.4 years.

D. Effects on Costs of Changing Initial Values. Fifty-eight separate changes of individual parameters are made to test their impact on the capital and operating costs or the costs of prospecting and exploration. In most instances the change was an upward or downward shift of 10% of initial value.

Three observations may be made.

The first concerns the use of most input variables in the cost estimation section to calculate capital and operating costs of discrete units of equipment in the 12 sub-sectors of the model. In general, a change in the value of a single variable results in changes in the capital and operating costs of one single unit, with minor changes in associated maintenance and fixed costs. These changes in costs are usually small in comparison to the total capital and operating costs of the project.

Second, there are several variables that are used throughout the model or in the processing sector and so affect costs in a number of sub-sectors. Changes in these have a larger impact on total project costs. One of these is the annual rate of ore recovery. It is a particularly critical variable since it affects the estimation of costs in all sub-sectors. A 10% reduction in the recovery rate of nodules results in a 5% decrease in capital and operating costs. The reduced recovery rate also leads to a decrease in gross revenues.

Three other variables to which the model demonstrates more than average sensitivity are indirect construction costs, contingency fees and engineering fees. These variables together comprise a factor applied to the direct costs figure in each of the sub-sectors of the processing sector. Thus each variable affects all components of processing costs, and the processing sector is the largest component of the total projects cost. A 10% change for indirect construction costs results in an increase of 2% on total capital cost. A change in the contingency fee from 15% to 20% gives an increase of 3% in project capital cost.

Finally, the group of variables associated with the lift system of the mining sector appears particularly sensitive. Changes in water depth at the mine site, in the pump submergence depth, and in the efficiency of separation of nodules from the lift discharge each results in changes of capital and operating costs of more than one million dollars. In addition, the change from an expected lifetime for the lift pipe from one year to six months results in an increase of $5.8 million in annual operating cost.

A second type of change in cost parameters concerns basic design or systems assumptions. The mining system used in the baseline model assumes that mining operations are conducted from a single mineship. The model is tested for two variations using two mineships, the first with all costs calculated from the same parameters used in the single mineship case, and the second making reasonable modifications in other costs. The results indicate significant increase in costs, an 11% increase in capital costs and a 17% increase in operating cost in the first variation. In the second, the capital cost is increased by 10%, but the operating cost is increased only by 7%.

In another analysis, distance from the port facility to the processing plant was increased from five miles to 25 miles and the distance between the processing plant and the waste disposal area was increased from 25 miles to 125 miles. These increases cause processing sector capital costs to go up from $342 to $392 million. Processing operating costs increase from $64.5 to $71.9 million.

Finally, analysis of the impact of using U.S. construction facilities and U.S. operating crews indicates a difference of approximately 7% in construction costs and as much as 6% in operating costs.

E. Effects on Economic Return of Changing Initial Values. In Chapter VI, an additional 60 analyses are made to examine the impact on the economic return estimates, of changes in the assumptions or values used in the baseline model. They comprise seven different areas:

1. Changes in revenue flowing to the project and its determinant components. Twenty-five percent increases and decreases in values are made in total revenue and price of nickel and cobalt; annual ore production is increased and decreased .5 million tons; a slow start-up with low production and high expenses is used; and the ore content of nickel and copper is reduced from 2.8% to 2%.

2. Changes in annual operating costs and its components. Twenty-five percent upward and downward shifts are made in annual operating costs, and energy, labor, materials and fixed operating costs.

3. Changes in total capital costs and its components. Twenty-five percent upward and downward changes are made in total capital costs and processing equipment, utilities, transportation, platform, pipe handling, lift system and waste system capital costs.

4. Introduction of delays. One and two year delays are introduced prior to the beginning of investment period, the beginning of commercial operations, and at both points combined.

5. Changes in assumptions concerning exploration and transportation costs. The daily charter rate of the research vessel is doubled and tripled; exploration is stretched out from two to 10 and to 20 years; and U.S. construction and crew costs are substituted for foreign costs.

6. Changes in assumptions concerning capital investment structure. Capital investment is allocated over four years at 5%, 15%, 45% and 35% instead of evenly over three years; 67% and no debt funding are tested; interest is payable on unpaid balance *vice* equal payments.

7. Changes in accounting and tax assumptions. A 6% escalation rate is introduced, capitalization vice expensing of R&D and exploration expenditures and straight line depreciation of declining balance with conversion are tested; and 22%/15% and no depletion allowances are used.

The results can be summarized in five statements of findings.

1. The largest impacts on economic return are from changing the level of revenue flowing into the project and from variables which are among the determinants of the level of revenue (market price of nickel, ore grade, production rate).

Parameters that either cut or add substantially to revenues will have a heavy direct impact on economic return. Twenty-five percent downward shifts in the level of revenues themselves lower IROR by 8.63% to 9.51%. Conversely, a comparable upward shift adds 6.31%. Twenty-five percent downward and upward shifts in the price of nickel lowers and raises IROR by 5.36% and 4.3%, respectively. Similarly, a drop in combined nickel-copper ore grade from 2.8% to 2% decreases the estimated IROR from 18.14% to 11.16%. Decreasing annual production of .5 million tons (a 16 2/3% change) reduces the IROR by more than two percentage points, while a comparable increase raises it by 1.4%. A slow start-up, with the first two years' production at 70% and 85% of projected rate, and higher than expected expenses, indicates a similar reduction in IROR.

These analyses suggest the relative sensitivity of the economic outlook to factors which are at least partially outside the control of the project's managers.

2. Twenty-five percent shifts in annual operating costs and in capital investment, two other major factors in determining cash flow (when capital investment is allocated on an annual basis), causes smaller changes in indicated economic return which, however, are large when compared to

most other changes made. Shifting annual operating costs of $100.5 million a year downward and upward by 25% causes the IROR to change from 18.14% to 15.07% and 20.72%, respectively. Similar shifts in total capital investment, for $493 million to $616 and $370 million changes the indicated IROR to 15.01% and 21.98%.

3. Delays of two years introduced in the planned project schedule before investment and between investment and commencement of operations also cause decreases in estimated IROR to 17.01% and, more significantly, 12.95%, respectively. When these two delays are combined, the IROR decreases further to 12.28%. One year delays causes smaller decreases. The analyses point up the impact of delay from any cause from the investor's viewpoint at the time it is considering commitment of funds, and particularly the effect of delay after those funds are invested.

4. The one other variable which indicates a relatively sizeable resulting shift in IROR is the use of debt funding. Changing the baseline assumption of 50% debt to no debt funding and to 66 2/3% debt produces IROR estimates of 15.41% and 19.53%, respectively.

5. The effects on indicated IROR of each of the other changes are, with two exceptions noted below, less than 1.1%. Many are in the neighborhood of 1/2%.

The two exceptions are the use of U.S. construction and crews, which reduces IROR to 16.26% and a 25% increase and decrease in processing equipment capital costs which lowers and raises IROR to 16.81% and 19.62%, respectively.

Thus the large majority of the variables tested for sensitivity or alternative assumptions had an impact on economic return measured in terms of one percentage point of IROR or smaller.

Three further observations should be made on these analyses. First, there may be variables to which the model may be significantly sensitive whose initial values were not changed. Second, a drop or increase of even a point of IROR implies not insignificant changes in discounted cash flows, their magnitude depending on when they occur. Third, actual experience is likely to involve several, perhaps many, changes in the values estimated in the model. It would take only a handful of small individual changes in values or assumptions, if they were all to move in one direction, to amount to a significant change in the project's economic prospects.

F. Analyses of Selected Policy Issues. Chapter VII of the study suggests in a preliminary, but illustrative way the uses in policy analysis to which the model might be put. Six policy issues are raised; most involve variables examined in Chapters V or VI.

The additional cost to the project of a policy requiring U.S. construction and crews is indicated to be $34.1 million in capital costs and $5.7 to 6.2 million per year in operating costs. This results in 1.88% drop in IROR. (Calculation of related benefits is dependent upon values external to the project.)

The effects are reviewed of policies which facilitate debt financing for the project, reduce the likelihood of delays in bringing the project into commercial production once an investment decision has been made, and grant or withhold depletion allowances. Analyses of these subjects are also reported on in Chapter VI.

The project's contribution to national income is approximated in the model by the sum of the discounted taxes paid and the discounted value of the profits distributed, using a social rate of discount in both cases. For the baseline model, the cumulative discounted contribution to national income over the entire life of the project is approximately $490 million. Approximately $260 million of this sum is received through taxes and the remainder is distributed to the owners of the project.

Finally, an examination of the methodology of evaluating policy measures to provide risk coverage against premature termination of the project is begun. Calculations of the values of the guaranty payments contained in H.R. 9 and H.R. 11879 are presented. These legislative proposals are illustrative in that their provisions bracket those of H.R. 3350 which in 1978 appears to be the focus of much consideration in the House of Representatives. The effect of risk coverage provisions on the project's NPV in the event of premature termination is presented for each year in the life of the project. When weighted with a subjective statement of the likelihood of such early termination and discounted at a selected rate, these values can indicate the prospective effects of risk coverage provisions on the ocean mining project. The impacts of resale value of the project are also shown.

G. Evaluation. What emerges is a picture of deep ocean mining which from the viewpoint of a prospective industry investor could provide an economic return which might realistically range from 15% to 22%, centering around the 18.14% which was the indicated IROR in the baseline study. The upper and lower figures are those generated by 25% upward and downward shifts of capital investment. They encompass the results from all analyses of changes in variables made in Chapter VI, excepting delays and large fluctuations of revenues.

The choice of discount rate by the industry investor creates a second range which has to be taken into account when considering the NPV associated with the project. For example, a company using a 12% discount rate and experiencing a set of conditions producing the lower IROR of 15% would see an NPV of $80 million, while the upper rate of 22% would provide an NPV of $190 million. (The baseline set of conditions would provide an NPV of $145 million using the same discount rate.) In contrast, the industry manager using a 20% discount rate would see an NPV of -$75, -$24 and $20 million for the lower, baseline and upper sets of conditions respectively. For a corporation using a discount rate, in the middle of the earlier two, the comparable NPV figures would be -$20, $35, and $90 million, respectively.

Finally, the prospect has been noted that most technical and economic unknowns and most policy options appear likely to have comparatively minor impact taken individually, while some that do appear to have larger impacts are at least partially beyond direct control. These findings strongly imply that the policy decision-maker must simultaneously evaluate the effects of individual policy or regulatory measures and pay attention to their combined effects on the economic prospects for deep seabed mining.

A COST MODEL OF DEEP OCEAN MINING
AND
ASSOCIATED REGULATORY ISSUES

CHAPTER I. INTRODUCTION TO THE STUDY

This study constructs cost estimates for a single first-generation ocean mining project located in the eastern central Pacific. This area, roughly bounded by lines of latitude at 5° and 20° north, and by 110° and 180° west longitude, is the ocean space in which aggregates containing nickel, copper, cobalt and manganese are found in commercially valuable quantity.[1] These aggregates, which are particularly rich in nickel and copper and chemically composed of metal oxides, clay and sediment, are now commonly called manganese or ferromanganese nodules.

Physically, nodules in the project area vary from one to four inches in diameter and are notably asymetric in shape. Most nodules are characterized by a flattened curvature of one surface and an exagerated curvature of the other surface.[2] Nodules are also found in the Atlantic, but not in commercial quality. Commercial recovery is determined by ore composition or grade by surface abundances and by recovery capacity.

The study makes reasoned assumptions as to these characteristics and then projects cash flows for a mining and processing operation handling three million tons of nodules a year over a twenty-five year commercial recovery period. The cash flow data form the basis for making analyses estimating the investment returns on the operation, and for projecting the values of the annual federal, state and local tax revenues generated over the life of the project.

A. Long and Short Term Policy Interests of the United States in Deep Ocean Mining

The capability to project the economic return accruing to the investor in an ocean mining project under a variety of different hypothetical conditions is the major tool used in this study for analyzing the impacts of various policy options confronting the U.S. government. The analysis of these impacts comprises the main function of the model created in this study.

The discernable U.S. policy concerns in deep ocean mining are both long and short term.

The long term interest attributable to the U.S. in the development of deep ocean mining stems from a desire to increase the world reserves of nickel, copper and cobalt. By the year 2000, if present world reserves of the above three commodities remain unchanged, projected world demand will have used up 48% of the presently known world cobalt proven reserve, 76% of the world proven reserve of copper, and 48% of the world proven reserve of nickel.[3]

To the United States, these figures are significant, for in 1975 alone, the U.S. imported 98% of its primary cobalt, 71% of its primary nickel and 15% of its primary copper.[4] By 2000, the U.S. probably will be totally dependent on other nations for its nickel and cobalt supply and partially dependent on the other nations for its copper supply.[5]

The projected additional supply of copper, nickel and cobalt from a single three million ton-per-year deep ocean mining operation would meet, by the year 2000, an estimated 20% of the U.S. demand for cobalt, 12% for nickel and 1% for copper.[6] Thus the increase in supply represented by a successful U.S. ocean mining industry could make the United States an exporter of cobalt and possibly nickel by the year 2000, as well as substantially increasing the reserves available to the United States.[7]

The future structure of the deep ocean mining effort may well be determined in the relatively short term in either or both of two negotiations in which the U.S. government, the North American mining industry and others are now engaged. One involves the consideration which the U.S. administration and Congress have been giving for the past several years to domestic legislation to promote and regulate deep ocean mining activity by U.S. citizens. The second is the Third United Nations Conference on the Law of the Sea. Here, successful culmination of the conference may turn upon resolution of deep differences among participants over the nature and international status of deep ocean mining. Following the 1977 summer session, expectations that a treaty in which the U.S. would participate could be negotiated appeared to be at a new low. Conversely, and in part reciprocally, the prospect for domestic legislation appeared on an upswing.

Both the international and domestic negotiations raise myriad policy options for the U.S. government. Most will affect the economic return to be realized from deep ocean mining and therefore the commitment of those who currently have the technological and financial resources to invest in the industry.

B. Use of the Study Model in Analyzing Domestic and International Policy Issues Bearing on the Profitability of Ocean Mining

The model created in this study provides insight into three kinds of questions reasonably expected to be of concern to policy makers in the deep ocean mining area.

The first concerns the technological and financial prospects for exploitation. A great many technical and financial determinants of the economic viability of deep ocean mining are necessarily subject to variation. One cannot tell with certainty what ore grade, annual production, mineral prices, processing efficiency, research and development costs, capital costs, operating costs, financial structure or pace of development will be. The perceptions of unknowns held by investors affect the amount of "risk" return sought over and above the company's earning rate on its current investments. The authors have made their best estimates of the values of such determinants in their "baseline" set of conditions. This study in addition permits such determinants to be varied. Varying these estimates and the factors from which they are calculated comprises one source of insight.

The second kind of question the model is designed to help answer concerns domestic legislation issues. The following are illustrative.

Time limits and work requirements may be imposed for different phases of the mining cycle. Requirements as to relinquishment of explored acreage would affect costs. Transportation of the ore in U.S. ships with U.S. crews may or may not be required. U.S. Maritime Administration financing may or may not be available. Political risk insurance may or may not be provided, and its existence or non-existence could affect the availability and cost of private funding. Whatever "right to mine" is provided would presumably, but not necessarily, be "exclusive". Environmental requirements, both as to sea and on-shore processing operations, may affect capital and operating costs, cause delays or alter siting or design plans. The tax status of the mining project, including the availability and values of percentage depletion allowance and investment credit, and the availability of debt financing would have impacts on the profitability of ocean mining. The determination of strategic needs for the minerals found in nodules could directly affect the extent of promotion instruments employed to encourage investment. Each of the above illustrations has its basis in legislative bills currently before Congress.

The third category concerns the international negotiations. Assuming negotiations continue on an international LOS treaty and assuming they envisage at least some projects operated by an entity other than the proposed international seabed authority or its subsidiary, there are numerous issues which would have an impact on mining ventures' economic return. Among them are royalties to be paid either to the authority or to the U.S. government in anticipation of an authority; the exploration costs involved in the "banking" scheme; costs of training and technology transfer requirements; duration of "right to mine" agreements; production limits; the splitting of the mining cycle into sub-cycles to be performed by different contractors; and, the time lags concomitant with the coming into force of any international agreement.

C. Technological Prospects for Exploitation

In 1876, the British research ship HMS Challenger discovered the existence of aggregated mineral lumps on the ocean floor in the Pacific.[8] Later explorations indicated their presence over much of the seabed.[9] It was not until the 1960's, however, that their recovery and processing on a commercial scale was forecast and industry began to commit funds to research and development aimed at creating an ocean mining industry.

At present there are four North American organizations developing deep ocean mining systems -- Deepsea Ventures, Kennecott Copper, International Nickel, and Lockheed Ocean Systems, a division of Lockheed Missiles Space Corporation. All four have formed consortia with domestic and foreign companies. All have selected the same basic design of a mining system, i.e., a bottom miner on the ocean floor connected to a surface ship by a nearly vertical pipe. Both a hydraulic air lift system and a mechanical pump system are being examined by the consortia.[10] In addition, one other group, Ocean Resources, Inc., a syndicate of over twenty mineral and energy companies, is developing the technology of the continuous line bucket lift system. The group is scheduled for disbandment following the licensing of perfected technology.[11]

The Deepsea Ventures group consists of U.S. Steel (Essex Minerals), Union Miniere (Union Seas), and Sun Ocean Ventures, Inc., with Deepsea Ventures as the project manager.[12] This group has filed a mine site claim and has completed pilot evaluations of the lift recovery and hydro-metallurgical processing systems. Deepsea is currently conducting large-scale evaluations aboard the R/V Deepsea Miner II.

The Kennecott Copper consortium consists of Kennecott Copper, Rio Tinto Zinc, Consolidated Goldfields, Noranda Mines, Mitsubishi, and BP Minerals, with Kennecott designated as the project manager.[13] This group has completed pilot scale evaluations of the sea floor mining vehicles and the hydro-metallurgical processing system. Further unspecified research and development is scheduled.

The International Nickel group consists of INCO, Arbetisgemeinschaft Meerestechnisch-Gwinnbare Rohstoffe (AMR), Sedco, Inc., Deep Ocean Mining Company, and Ocean Management, Inc., as the management contractor.[14] This group is continuing development of its processing technology and had reportedly scheduled late 1977 at-sea tests using the Sedco 445 drill ship and the R/V Valdivia exploration data.

The Ocean Minerals Company consists of Lockheed Ocean Systems, Amoco Minerals Company, Billiton International Metals, B.V. (a subsidiary of Royal Dutch Shell), and Bos Kalis Westminster Ocean Minerals, B.V., with Lockheed as project manager.[15] The group has conducted on-land evaluation of some components of the mining system and lab evaluations of the hydrometallurgical processing system. The group planned to start at-sea tests in late 1977.

Thus far, these groups collectively are estimated to have spent $100-150 million on prospecting, exploration, research and development.

Elsewhere in the world, a French consortium has been formed around the Centre National pour l'Exploitation des Oceans (CNEXO) and consists of the Commissariat à l'Energie Atomique, the Société Metallurgique le Nickel and the Bureau de Recherches Géologique et Minières with the Chantiers France-Dunkerque du CNEXO as the project manager.[16] The consortium is primarily a research and development group concentrating on R&D up to the prototype operations of a mining system.

The major technical uncertainties referred to in the prior section which are associated with a deep ocean mining system can be divided into five major categories -- those associated with the bottom miner, lift system, surface system, transportation system, and processing system.[17]

The technology surrounding the mining system, comprising the bottom miner, lift system, and surface system is probably known with least certainty. While some technology can be drawn from current offshore drilling operations, government research and development programs, and land mining systems, many of the technical uncertainties must remain until actual on-site experience is gained. The collector head's capability to separate bottom clay, the stability of the pipestring, the optimal depth of the lift pump, the maneuverability of the dredge head, and the impact of surface discharge on the environment of the ocean are all likely to remain question marks until the system is operating on station.[18]

Another uncertainty is the speed with which competitors are believed to be advancing their technological capability. The consortia led by North American firms have stated various beginning production dates in the 1980s. The potential for technical advance in the uses for manganese, presently regarded by some of the consortia as the "throwaway" ore, is yet another question mark.

D. Informing Policy Makers on the Economic and Financial Aspects of the Institutional Decisions

The resolution of the policy issues identified in the prior section will largely be political in nature, in that decisions will result from efforts to balance international, national and private interests. The premise of this study is that the public decision-makers on these issues, who also must take cognizance of the technological uncertainties referred to in Section C, will be beneficially informed by having available to them estimates of the financial or economic valuation of the private and national interest which are based on detailed considerations of cost. With these data, the impact of the available options may be better understood.

For the private sector, that interest is in great part represented by the economic return on capital invested, i.e., the profit to be expected from an investment in deep ocean mining. Most of this study focuses on approximating the financial return to the investor on one ocean mining project. Considerations such as the economic impact on the wider corporate setting in which an individual project is placed or the importance to the company's competitive position in making an ocean mining investment -- apart from return considerations alone -- are not taken into account in the cost estimations or return analyses. They may be accounted for, however, in judging how the company will discount the future cash flows accruing from the project.

The economic return to the public sector in the form of taxes less any transfers out to the private sector, when added to the return to the investor, approximate the total contribution of the project to national income. Ideally, the decision-maker ought to be able to take into account the return to both the private and public sector when weighing the impact of different options on the above issues.

E. The Model

This study has developed a simulation financial model of a "typical" deep seabed mining operation. A fairly detailed estimate has been made of the capital costs of the major components of a five-phase mining operation cycle: prospecting, exploration, mining, transportation and processing. The operating costs have been similarly estimated and aggregated. The major components are: energy, labor, materials, fixed, and miscellaneous costs. The cost estimation for each phase was made by determining as closely as possible the costs of assembling and operating the equipment necessary for that phase. Over 75 percent of the cost estimates of equipment components have been developed independently of the four major industry consortia described earlier. The authors did, however, receive much beneficial information and critical comment on the model from sources.

The aggregated cost estimates are then provided as input for a financial analysis section of the model, the main objective of which is to generate the cash flow projections over the life of the hypothetical project.

The model is presented in several layers of technical detail to suit the preferences of a variety of readers and users. First, Chapter II provides a general background on the technology of deep ocean mining which is structured on the major phases: prospecting, exploration, mining, transport and processing.

Next, Chapter III provides a description of the construction of the model for each of these phases and for the financial analysis portion. The major input components of the financial analysis sector of the model are those which produce a cash flow estimate for each year of operation, e.g., gross revenues, total capital investment costs, operating costs (both taken from the cost estimates), interest charges and taxes.

Finally, each section of Chapter III has a counterpart appendix which provides a much fuller, more technically detailed description of the particular sector of the model. The variables describing the parameters of the model, the initial values assigned them in our "baseline" model, the equations which comprise it, the technical premises from which values were derived, and the sources for those values and assumptions are laid out in the respective appendices.

Any model such as ours is subject to abuse. Evaluators of the output can present particular results out of context and use the results to support a particular point. Or a user can so change the variables that they no longer represent valid approximations.

To avoid misuse of the model, we have delineated the underlying assumptions for independent program variables and frequently defined explicit bounds for them at the end of appropriate sections of appendices.

In a brief Chapter IV, the values of all the variables or parameters in the initial or "baseline" model are presented together.

The model is made for use. The input variables used in the model can be easily changed at the will of the analyst, the person using the program. The analyses contained in this study provide a basic beginning, but the intent has been to make the model a tool useful in informing policy-makers as new issues become timely.

F. Analysis Based on the Model

Chapter V presents the aggregated capital cost and operating estimates for what is termed the "baseline" model, that is, the operation with the parameter values stated in Chapter IV. Over 50 of the initial parameter values have been varied by 10 percent on one or another side of the initial value to see which were most sensitive in affecting capital and operating costs. Also, the major sub-components of total capital and operating costs were varied to examine their impact on the total figures. And in the case of certain variables, different options were tried where, as in the case of the number of mineships employed, there appears to be reasonable choice or proposed practice appears to vary among the consortia. These analyses are presented in Chapter V.

Chapter VI concerns basic financial analysis. The project's gross revenues based on metal value concentrations, process recovery efficiencies and metal market values are projected, and the cash flows are calculated for each year of the project life. From these sums, three measures of economic return are calculated and displayed: Net Present Value, Internal Rate of Return and Payback Period. The analysis then proceeds in the pattern established in Chapter V to examine both the major components of gross revenue and other selected variables for the impact that varying them has on the measures of return. The concept of delay of operations as a detrimental cost is also introduced.

As stated at the outset, the model has been developed to examine policy options faced by U.S. decision-makers. Several, though by no means all, of these are examined in Chapter VII. This chapter represents the kind of use for which the model is intended. The analyses selected are concerned with the values of U.S. domestic legislation to the individual project and to the nation.

Each of the analyses in Chapter VII examines the effect of changing, delaying or adding something in the "baseline" model. The nature of the analyses points up an important fact concerning the whole study: this study is <u>not</u> a basis for a potential investor's decision-making concerning ocean mining. Nor is it a cost estimate of the kind that would be made by an operator planning an actual operation, for these kinds of costs are made only as a specific equipment list is assembled and the goods placed on order. What the authors believe the study has provided are reasonably detailed and accurate estimates to serve as a basis for assessing the comparative impacts a broad range of policy and regulatory options will have on a typical deep seabed mining operation.

Second, very many of the cost estimates made here for a first generation mine operation can be expected to be different for second and subsequent generation operations. Exploration costs, ore grade and abundance, and cost of processing technology are only a few among the many that are likely to be different.

Chapter I Notes

1. David R. Horn, "Worldwide Distribution and Metal Content of Deep-Sea Manganese Deposits," in Manganese Nodule Deposits in the Pacific, Honolulu, Hawaii, 1972, p. 47.

2. Walter Kollwentz, "Prospecting and Exploration of Manganese Nodule Occurences," in Manganese Nodules - Metals from the Sea, Metallgesellschaft AG, 1975, p. 12.

3. Bureau of Mines, Mineral Facts and Problems, U.S.Department of Interior, Washington, D.C., 1975, p. 32.

4. Ibid., p. 12

5. Ibid., p. 22.

6. Ibid., p. 22.

7. Conrad G. Welling, "Ocean Mining Systems," Mining Congress Journal, September 1976, pp. 46-47.

8. D.R. Horn, B.M. Horn, and M.N. Delach, "Distribution of Ferromanganese Deposits in the World Ocean," in Ferromanganese Deposits on the Ocean Floor, R. Horn, (Washington, D.C. 1972), p. 9.

9. Ibid.

10. Conrad G. Welling, "Next Step in Ocean Mining - Large Scale Tests," Mining Congress Journal, December 1976, p. 46

11. Mining Engineering, April 1976

12. Welling, "Next Step in Ocean Mining - Large Scale Tests," p. 50.

13. Ibid., p. 51.

14. Ibid., p. 50.

15. Ibid., p. 51.

16. Centre National Pour L'Exploitation Des Oceans, Bulletin D'Information, Numero 97, Janvier 1977, p. 23; and Numero 100, Avril 1977, p. 6.

17. Welling, "Next Step in Ocean Mining - Large Scale Tests," p. 46.

18. Ibid., p. 47.

CHAPTER II. OVERVIEW OF THE TECHNOLOGY OF DEEP OCEAN MINING

In some ways, most notably in processing technology, deep ocean mining has certain similarities to conventional mining operations conducted on land. The major difference, of course, is the nature of the ore body and the methods developed to recover the ore. Manganese nodules are widely distributed around the world and are found in both fresh and salt water. But it is only in nodules found in the deep ocean that the content of valuable metals is high enough to be of commercial interest, and the metal content varies greatly in different parts of the ocean, as is shown in Table II-1.

Table II-1, Illustrative Chemical Compositions of Nodules[1]

	Pacific			Atlantic		
	max.	min.	avg.	max.	min.	avg.
Mn	41.1%	8.2%	24.2%	21.5%	12.0%	16.3%
Fe	26.6	2.4	14.0	25.9	9.1	17.5
Co	2.3	.014	.35	.68	.06	.31
Ni	2.0	.16	.99	.54	.31	.42
Cu	1.6	.028	.53	.41	.05	.20

Nodules have elicited the interest of minerals companies for their content of nickel, copper, cobalt and manganese.[2] Because of the relatively low content of these minerals, many of the nodule deposits, and all of the more easily accessible ones, are of little interest for commercial development at the present time.[3] The richest of the explored nodule deposits are found in the Pacific Ocean about 1000 miles east-southeast of Hawaii. These nodules provide a rich ore of nickel and copper, with traces of cobalt.[4] The nodules are easily crushed and are amenable to several forms of hydrometallurgical processing.[5] The depth of the region is approximately 18,000 feet.[6] The seabed consists of gently rolling abyssal hills of 180 to 600 foot relief, which are covered by pelagic sediment that forms a seabed of siliceous ooze.[7] Bottom life in the region is relatively sparse, with a biomass measured in the range of .01 to .05 grams per square meter.[8]

The properties of the nodules and of the mine site that affect the design and operation of the mining system described in this study are listed in Table II-2, along with the values assigned to them in this study.

Table II-2, Model Mine Site Characteristics[9]

Water Depth		18,000 feet
Distance to Port		1750 nautical miles
Surface Abundance		2 pounds/square foot
Nodule Diameter		.125 feet
Drag Coefficient of Nodule		.5
Density of Dry Nodules[10]		128 pounds/cubic foot
Metal Content:	Nickel	1.5%
	Copper	1.3%
	Cobalt	0.25%
	Manganese	25.0%

A. Preparation for the Mining Operation

The exploitation of manganese nodules must first begin with a research program to develop mining and processing technology that will profitably recover nodules from the seabed and produce the desired metals in marketable form. Because of the large sums of money required in these projects (on the order of $500 to 700 million per mining operation) companies have formed consortia to share the cost of the programs and to spread the risks of the projects among consortia members. In addition to the development of new technology, the research program must include an assessment of the qualities of potential minesites. This is the beginning of the prospecting and exploration phase of the mining operation. This phase may be conducted concurrently with the research and development phase, or the program may be initiated after the beginning of the R&D

phase, and continued during the investment and operating phase of the program.

B. Commercial Mining

The commercial recovery of nodules from the seabed has been made possible by the development of methods for moving large quantities of nodules from the sea floor to the surface. The system that is proposed to accomplish this task is a fluid lift system that mixes the nodules in a slurry with sea water and pumps the mixture to the surface. There are two designs that are being actively considered by the mining industry for the first generation mining systems: conventional slurry pump and air lift. The first system uses a submerged multi-stage centrifugal pump to force the mixture to the surface. An analysis of this system is presented in Appendix B. The analysis is incorporated into the computer model and is used to obtain capital and operating cost estimates for the mining sector.

The airlift system injects air into the slurry to reduce its density so the three-phase mixture of air, nodules, and sea water is forced to the surface. Deepsea Ventures, which conducted tests of this system in the Atlantic in 1970 and is currently testing equipment in the Pacific, plans to use the air lift method. International Nickel Company and Kennecott Copper Corporation are considering both conventional pumps and the air lift method. The three-phase flow of the air lift requires extensive testing before the power requirements and the capital cost of the system can be determined. Consideration of such a system is beyond the scope of this report. It can be assumed, however, that the air lift system will be used in place of a hydraulic system only if it makes the operation more profitable. Thus, the assumption made in this study that a two-phase system will be used is conservative.

The development of the lift system, while critical to the exploitation of the nodules, is only part of the mining system. A complete mining system may be composed of one or more mining vessels, each with its own lift system and nodule collection device that is pulled along the seabed to gather the nodules together and feed them into the lift. Proposed mineships are similar to existing deep water oil drillships and are expected to be about 800 feet in length. The pipe string that reaches to the sea floor has a diameter of about two feet. The pumping unit is submerged in order to avoid cavitation of the pump impeller while it generates the pressure to lift the nodule slurry to the surface. The bottom of the pipe string is either weighted or held down by a hydrodynamic depressor to maintain the pipe in a nearly vertical position while the collecting device trails behind, skimming the surface of the sea floor with minimum force exerted on the sediment. In this manner the collecting device can be crudely guided relative to the lift pipe by remote command from the surface.

The details of the capital components of the mining system and the major areas of operating cost are described in Chapter III. A more detailed examination of the operation of the hydraulic lift and its influence on the design of the mining system is provided in Appendix B along with an account of the equations of the computer model that pertain to the mining system.

C. Transportation

As with any ore that is mined outside of the United States and processed domestically, the ore must be transferred by ship from the mine to the processing plant. In the case of ocean mining, the ore must be temporarily stored on board the mine ship until the arrival of the transport vessel. The nodules may be transferred to the transport either as a slurry or as bulk cargo. We have assumed in this model that all transfer of the nodules is done as a slurry.

D. Processing

The third, and most costly, sector of the ocean mining operation is the processing sector. The minerals industry has developed a variety of metallurgical processes for the recovery of metals from nodules. Both hydrometallurgical and pyrometallurgical methods have been developed, based in part, on methods developed for the recovery of metal values from copper and nickel oxide ores. Hydrometallurgical techniques have been favored, although not by all of the mining companies, because the metal oxides in the nodules are finely dispersed throughout the nodules, which makes mechanical concentrating of the ore impossible. The selection of a specific process depends, among other things, on the decision whether or not to market manganese, on the availability and cost of energy and reagents for the process, on the impact of environmental regulations, and on each company's past experience with similar processes.

One promising system utilizes a reduction roast and ammonia-ammonium carbonate leach to recover the nickel, copper, and cobalt while leaving the iron and manganese in the tailings. The technology for such a system has been well documented in its application to nickel and copper oxide ores and it has been chosen as the basis for the development of the processing sector of the cost estimation model.

The equipment related directly to the processing of the nodules and to the recovery of the metal values comprises a large part of the cost of the processing sector, but costs related to transportation of the ore, disposal of the waste products, purchase of land and development of the port facilities and process site are important. These costs are discussed in more detail in Chapter III, and the portions of the computer model that describe the processing sector are found in Appendix D. Also in Appendix D, the details of the processing equipment that describe the ammonia leaching system are presented in a manner that serves as a pattern to allow the modeling of other metallurgical processes.

Chapter II Notes

1. John Mero, The Mineral Resources of the Sea, (New York, 1965), p. 180.

2. Udo Boln and E. Muller, "Economic Aspects of Manganese Nodule Deep Ocean Mining," in Metallgesellschaft AG - Review of the Activities, Edition 18, p. 44.

3. Walter Kollwentz, "Processing and Exploration of Manganese Nodule Occurances," in Metallgesellschaft, pp. 13-14.

4. Horn et al., "Copper and Nickel Content of Ocean Ferromanganese Depostis," in The Origin and Distribution of Manganese Nodules, ed. Morganstein, pp. 77-82.

5. J.C. Agarwal et al., "Processing of Ocean Nodules," presented at the 104th Annual Meeting of AIME (New York, 1975), pp. 1-3.

6. Horn et al., p. 78.

7. Ibid., p. 77.

8. O.S. Roels et al., "Environmental Impact of Two Manganese Nodule Mining Tests," in Manganese Nodule Deposits in the Pacific, (Honolulu, 1972), pp. 129-146.

9. Horn et al., pp. 77-83.

CHAPTER III. THE DEEP OCEAN MINING MODEL

This chapter describes the study's model in non-technical terms in sufficient detail to provide a basic understanding of its construction. Each major system sector discussed in the following sections has a counterpart appendix which provides technical specification. In the initial paragraphs below, a brief overview is provided of the model's structure.

The model is developed in two parts: the cost estimation of the technical model, and the financial analysis of the capital costs, operating costs, and revenues derived from the sale of products.

The costs that are incurred during the life of the ocean mining project are scheduled over four time periods. Expenditures for research and development and for prospecting are scheduled at the beginning of the project. After the completion of these expenditures, the exploration program and capital construction program begin. Although these two programs begin at the same time, they are independent and may be of different lengths. The operating costs of the project are scheduled during the operating period, which follows the completion of the capital investment period. The cost estimates are based on technical and environmental parameters that describe the research and development, prospecting, exploration, capital investment and operating phases of the mining operation. A summary of the input variables appearing in the model is found in Chapter IV.

Capital costs are grouped into three major categories: the mining sector, the transportation sector, and the processing sector. Each of these three sectors is further broken down into smaller sub-units. The basic capital cost blocks of the model are graphically depicted in Figure III-1.

Operating costs of the three sectors are broken down into five groups: energy costs, labor costs, material costs, fixed costs, and miscellaneous costs. Fixed costs represent

— — —

Figure III-1

Structure of the Capital Cost Estimation Section

Platform Handling Pipe Handling Power Plant Lift System Navigation & Control	Mining Sector	Mining System
Transport Ships Slurry Systems	Transport Sector	
Process Equipment Utilities Site Development Buildings Waste Disposal	Processing Sector	

— — —

capital proportional costs and include such costs as insurance and state tax. Each of the five major categories of operating costs is further broken down as a part of each sector of the model. The operating cost blocks of the model are graphically depicted in Figure III-2.

— — —

Figure III-2

Structure of the Operating Cost Estimation Section

Energy Labor Material Fixed Miscellaneous	Operating Cost

— — —

The aggregated capital costs and the aggregated operating costs become the major inputs into the second main part of the model: the financial analysis program. Annual cash flow is calculated from the inputs and in turn is used in an economic return analysis of the operation.

The financial analysis program comprises five major factor groupings: time factors, financial factors, economic factors, technological factors, and policy factors. These factors are used to determine project scheduling, compute gross revenues, allocate capital investment, calculate interest and depreciation, determine taxes, and define the project time designator. These are, in turn, analyzed to provide estimates of Net Present Value (NPV), Internal Rate of Return (IROR), and Payback Period. The initial values of the factors, the annual values of the intermediate determinations, and the project values for NPV, IROR, and Payback Period are part of the computer program print-out. Graphic portrayal of the major components of the financial analysis program is represented in Figure III-3.

A. Prospecting and Exploration

The selection of a minesite for deep ocean mining operations will be made in two stages. The first stage is prospecting, which consists of the preparation of a particular area for mining operations.

1. Prospecting

The aim of the prospecting program is to reduce a large, identified area of the seabed, which may include extensive low-grade deposits, to an identification of a smaller area that consists of the richest deposits. The process may typically be conducted by a research ship that recovers samples and conducts tests at widely spaced points. One source suggests distances of approximately 200 kilometers. The results of this survey are used to locate the areas that include the richest deposits. The research ship then repeats the operation at intervals about half as great. The results are examined to locate the most desirable

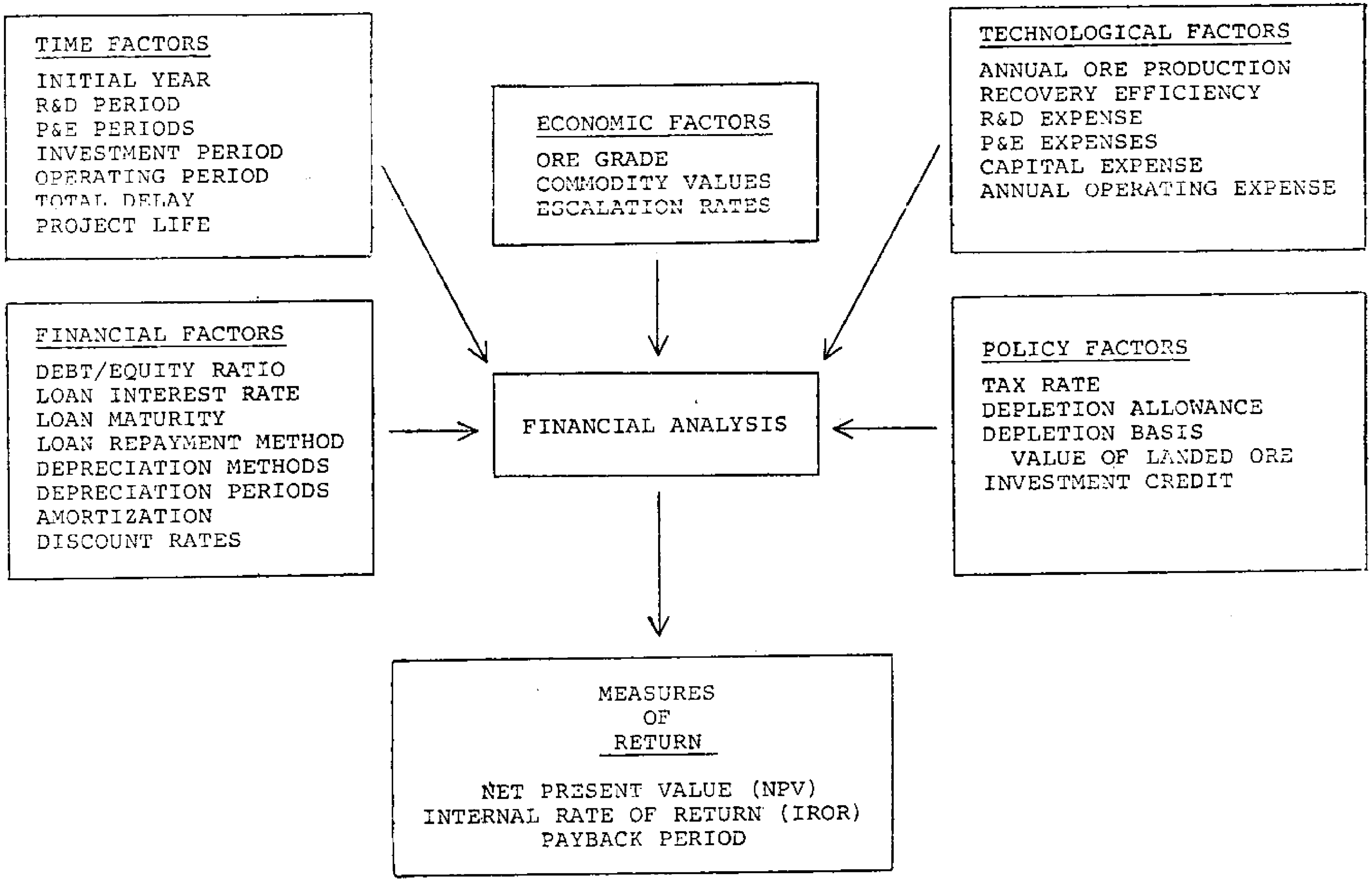

Figure III-3
Major Components of the Financial Analysis Section

site and the ship is sent to that region. The survey ship samples the area on a detailed grid at points separated by about 25 kilometers, or an eighth of the original interval. This survey completes the prospecting operation.

2. Exploration

The objective of the exploration program is to obtain information for the final selection of the mine site. Data are obtained from a series of soil samples from a specified grid in the form of a sonar and television record of the entire site.

Soil samples may, for example, be obtained from a grid with a point separation of two kilometers, at a rate of 20 samples per day, by the use of a sampling device that falls to the seabed, plunges into the soil, releases its ballast and returns to the surface with the sample.

A map of the mining region may be obtained by the use of an integrated instrument system consisting of a precision depth recorder, a television camera, and a side scan sonar. The depth recorder is mounted on the research vessel to record the terrain of the site. The television camera is towed near the sea floor so the size and distribution of the nodules can be seen. The sonar is towed farther from the sea floor so it can produce a record of the terrain 100 meters to each side of the vessel's path.

The first step in determining the cost of the prospecting and exploration phase of the deep ocean mining system is to estimate the size of the minesite that will be needed to provide ore for the entire life of the mining operation. In this model, the size of the minesite that must be explored prior to the commencement of commercial operations is determined from seven factors:

1) the projected operating lifetime of the project;
2) the annual production rate of dry ore from the site;

3) the average surface abundance of nodules in the regions of the site that will actually be mined;
4) the sweep efficiency, which represents the fraction of the desired nodules that are actually passed over by the mining unit;
5) the efficiency of the collector, which is the fraction of the nodules that pass under the collecting unit that are sent to the surface;
6) the water-nodule separation efficiency, which is the fraction of the nodules sent to the surface that is recovered from the lift discharge; and,
7) the area of the minesite actually available for mining which excludes areas of low-grade deposits or unfavorable topography.

The costs of the exploration program are composed of the cost of the research vessels used in the mapping and bottom testing surveys described above, and for the shore-based research and analysis team. The vessel costs for each type of survey are expressed in dollars per unit area of the minesite. These costs are based on a rental rate for the research vessel of \$5,000 per day, but this assumption may be changed by an appropriate command to the computer model. A detailed examination of the requirements of the surveys is found in Appendix A, where the costs for the mapping and soil sampling surveys are found to be 432 $\$/km^2$ and 97 $\$/km^2$, respectively. The cost of the research team is considered to be independent of the size of the minesite and is assigned a value for the entire program of \$330,000 per year. The basis for this estimation is also given in Appendix A.

The cost of the mapping survey and the soil survey are multiplied by the size of the minesite and are added to the cost of the research staff to produce the total exploration cost.

The parameters used in the calculation of costs of the prospecting and exploration phase of the mining operation are summarized in Chapter IV.

B. Mining

Deep ocean mining has become technically possible with the development of methods for moving large quantities of nodules from the sea floor to the surface. A mining system for manganese nodules that resembles the current design philosophy of the mining industry may be divided into five sub-sectors, which are shown in Figure III-4. In the cost estimation section of the model, the costs for the sub-sectors are estimated and summed to obtain the total capital investment in the mining sector. Each of the sub-sectors is briefly described below.

— — —

Figure III-4, Structure of the Mining Sector

	Platform	
	Pipe Handling System	
Pipe String Pump Unit Bottom Unit	Power Plant	Mining Sector
	Lift System	
	Navigation & Control	

— — —

1. Mining Sector Capital Costs

a) The Mining Platform

The platform is a ship that is configured in a manner similar to conventional deep water oil drill ships. The ship provides space for the installation of a power plant, for storage of the pipe string and pump system, and for the pipe handling system and the motion compensating platform. In addition, the ship must provide temporary stowage for the nodules that are recovered between arrivals of the transport vessels. The space allocated for nodule stowage may run about 400 feet of the total length of the mining vessel for a mining operation that recovers three million dry short tons of nodules per year and is serviced by transport vessels at six day intervals. The calculations underlying these and other assumptions for the mining sector are found in Appendix B.

b) Power Plant

The power plant must provide power for the operation of the lift system and for the forward propulsion of the vessel and lift pipe through the water. These requirements greatly exceed the capacity of conventional drill ships. In the cost estimates used in this model, it is assumed that the power plant that is included in the cost estimate of the mining platform is used to supply ship service power, but that the power for lift and propulsion is supplied by a separate power plant.

c) Pipe Handling System

The pipe handling system includes equipment to move pipe from the storage area to a pipe suspension tower and to assemble the pipe string. A major part of this system is the motion compensating platform on which the tower is constructed. This platform supports the pipe string, and it compensates for motion of the ship that would add to the stresses on the pipe and lead to early failure of the string.

d) Lift System

The lift system comprises three major sub-systems: the pipe string, the pumping unit, and the bottom (or collector) units. These units, in turn, are broken into smaller groups of equipment. The pipe string is composed of a steel pipe that extends from the mineship to the sea floor, and of couplings that connect the individual lengths of the pipe. The cost of the pipe is determined by the diameter of the pipe (which is determined by the model), the wall thickness of the pipe, the price of fabricated pipe, and the depth of the water at the minesite (which may be selected by the program operator). The number of couplings is equal to the number of 30-foot sections of pipe required to reach the seabed. The cost of a single coupling is entered by the program operator and the computer calculates the total cost of the couplings.

The cost of the pumping unit includes the cost of a pump, a motor, and a housing to enclose the pump and motor, as well as the cost of installation materials and labor and construction indirect costs and sub-contractor fees. The cost of the pump is estimated from the pump power requirement that is determined by the model. The cost of the motor is also determined from the required pump power, but a factor expressing the pump efficiency is included in the calculation. The cost of the housing is assigned a fixed cost regardless of the size of the mining operation.

The collecting units used in this model are assumed to have a fixed capital cost regardless of the size of the mining operation. This assumption is made in light of the assumption that the major part of the investment in the bottom unit is in the remote observation and control equipment that is mounted on the unit. The initial capital investment in collecting units includes the purchase of enough units to allow the system to operate for one year before needing new units.

e) Navigation and Control

The positioning accuracy of the mining operation requires state of the art components, including satellite navigation systems and dynamic positioning units. The cost of the navigation and positioning system is considered to be a fixed cost for the mining system.

2. Mining Sector Operating Costs

The operating costs of the mining sector are divided into give groups: energy, labor, materials, fixed (capital related), and miscellaneous costs. Each of these groups is calculated from a more detailed analysis of the costs that is performed within the computer model. The structure of the operating cost analysis is summarized in Figure III-5.

Figure III-5
Operating Cost Structure in the Mining Sector

Ship Propulsion Pump Operation	Energy	Mining Sector Operating Cost
Crew Maintenance Labor	Labor	
Pipe Replacement Bottom Unit Replacement Maintenance Materials	Materials	
Insurance	Fixed	
General Administration	Miscellaneous	

Energy costs in the mining sector are calculated from the power requirements for the lift pump and for the ship's propulsion system. Power consumption of the lift system is determined by the computer model, as is the propulsion power, by means of an optimization loop that determines the characteristics of the lift system that result in minimum total power consumption. Details of this section of the model are provided in Appendix B. The power requirement, the total number of operating hours per year, and the price of fuel per horsepower-hour are used to determine the annual energy costs for the mining sector.

The labor costs of the mining sector include normal operating labor of the mineship plus the annual labor charges that result from maintenance. In this model two-thirds of the annual maintenance costs are allocated to labor. The labor cost of the ship's crew is assumed to be a constant, regardless of the size of the ship or the number of days spent at sea.

The maintenance costs are estimated from the total capital investment in the mining sector.

The materials section of the operating cost is also composed of two types of charges: replacements of the pipe string and bottom unit, and general maintenance costs. Replacements costs are determined by the lifetime of the equipment or the estimated mean time between failures. The maintenance costs are estimated from the total capital investment in the sector, and the fraction of maintenance charges not allocated to labor are charged to materials (refer to the description of labor charges in the preceding paragraph).

Fixed costs are the charges that are proportional to the capital investment in the mining equipment. These costs may include insurance payments and taxes that are charged on the ship. It is presently assumed that the fixed costs of the mining sector are limited to insurance payments, and that these payments are proportional to the investment in the mining platform.

Miscellaneous costs cover the general administration costs of the mining sector and are estimated as a fraction of the capital investment in the entire sector.

3. Multiple Mineship Mining Systems

The annual production of nodules from the ocean floor may be obtained by a single mining ship and system, or the production may be divided between two or more mineships. When multiple mineships are used in the computer analysis, the capital and operating costs for a single ship in the multiple ship system are determined and these costs are multiplied by the number of ships to determine the capital and operating costs for the mining sector. (See Section D 1 of Chapter V for further analysis.)

C. Transport

The transportation system for delivering mined nodules to shore is based on rapid slurry transfer of nodules from the mineship to the transport ship and from the transport ship to the processing plant. It is assumed that as the nodules are mined, they are dewatered and stored in the hold of the mineship. Upon arrival of the transport vessel, the nodules are reslurried and pumped into the transports. The nodules are again dewatered, taken to port, reslurried and pumped into shoreside holding ponds.

1. Transport Sector Capital Costs

The capital cost of the transport system is calculated as the sum of the capital cost of the transport ships and the slurry system.

Figure III-6

Components of Transport Sector Capital Cost

Transport Vessels Slurry System	Transport Sector Capital Costs

a) Transport Vessels

The cost of each transport vessel is calculated as a function of its deadweight tonnage.

The programming procedure identifies the combination of size and number of transport ships needed to service each mineship given its size and distance of the minesite from port. The model can accommodate any number of mineships but they must all be the same size.

The most efficient means of transporting the nodules is by using the least number of the largest ships possible. In general, this condition minimizes the capital costs, in that a fewer number of larger ships adding up to a given sum tonnage costs less than a greater number of smaller sized ships of the same sum tonnage. For example, two 60 thousand ton vessels would cost less than three 40 thousand ton vessels. This objective also minimizes operating costs (discussed below) which are fairly constant, except for fuel and insurance, for any size ship.

The limiting size of the vessels is determined in part by the port the vessels will use. Assuming U.S. lower West Coast processing sites where port limitations are in the 45-60 foot draft range, an 80 thousand ton vessel would be about the largest vessel that could be adequately handled. This restriction can be changed to suit the user and should be changed when more specific information regarding the characteristics of an intended port is known. The program has been pre-set to a limit of 80 thousand tons. If Gulf Coast ports are to be considered, the limiting factor would probably be the depth of the Panama Canal. "Panamax" size carriers are generally in the 55-60 thousand ton range.

The distance from the minesite to the intended port can be varied. However, it can not be varied for each individual mineship.

In calculating the number and sizes of the necessary transport vessels the model will first try to identify the fewest number of ships possible. It will then determine the size of these ships. If the ships exceed the allowable limit, the program will set the maximum ship size to be the size of the mineship and then identify how many ships of that size are necessary. If the mineship is larger than the limiting value of the port, the transport vessels will be set to that size and the number required will be established. This number will usually not be an integer number. In these cases, the model will choose the next lowest integer number of ships the size of the mineship or the limit value (whichever governs) plus one smaller ship -- called a "kicker" in this study. If the smaller ship is less than 30 thousand tons, the program will set it to 30 thousand tons and then determine the required size of the other ships. The figure of 30 thousand tons is used as a lower limit on transport vessel size.

In a case where only one mineship is used and only one transport is needed to service it, the program will require that at least two transports be used. This precaution is taken to insure that in case of transport breakdown, the whole operation would not be halted.

The model uses mineship size, accumulation rate of ore, and loading and unloading time as constraints. The loading and unloading time is the time it takes to empty or fill the transports and is not directly dependent upon the mining rate.

b) Slurry System

The discharge and load rate of the slurry system is set at 3500 long tons per hour. The system uses 18 pumps (nine at the shore facility and nine at the minesite). The pumps are estimated to handle a load of about 7000 GPM each, of fluid equivalent, pumping against a 60 foot head. Each pump is rated at 105 HP. The cost for each pump is figured at $64,900. The total cost for the pumps is $1.17 million and the cost of the pipeline and pumpyard components is $.63 million. This total slurry system cost of $1.8 million is pre-set into the program but can be changed.

2. Transport Sector Operating Costs

The operating costs of the system are divided into the fuel, insurance, labor, stores, subsistence, maintenance and repair and miscellaneous costs. (See Figure III-7.) There is also a lay-up cost identified. This cost refers to the cost that would be realized just to keep the transportation system

Figure III-7
Operating Cost Structure in the Transport Sector

Fuel	Energy	Transport Sector Operating Cost
Crew Salaries Maintenance Labor	Labor	
Subsistence Stores Maintenance Materials	Materials	
Insurance	Fixed	
Miscellaneous	Miscellaneous	

in operating condition even if it were not actually being used. This situation might occur if the mining operation had to shut down for some reason.

Fuel costs are calculated as a function of deadweight tonnage per knot per day. The program employs a multiple of dollars per day per deadweight ton per knot and then multiplies this number by the given speed, the size of the vessel and the number of work days per year. The regression curve for this function was constructed using ship speeds between 14.5 and 16.25 knots. The speed of the transports, which is set at 15 knots, can be changed but should not be set beyond this range.

Insurance costs vary with the capital cost of the ship, which is in turn a function of its size.

Labor is considered constant for any size ship and is set at $1.8 million for a ship employing foreign crews and $3.25 million for a ship employing American crews.

Maintenance and repair costs are calculated as a percentage of the capital cost of the ship. This percentage is then multiplied by the capital cost of the ship to find the actual maintenance and repair costs.

Stores, subsistence and miscellaneous are all considered constant for any size and are, respectively, \$.235 million, \$.150 million and \$.225 million per ship.

There is an option to the user pertaining to the national source of certain costs. The ship capital cost and the labor cost are specifically defined to be either foreign or domestic. This is a decision that is user controlled.

The fuel, insurance, miscellaneous, stores and subsistence costs are not dependent upon whether foreign or domestic crews are used. It was assumed in the model, that since the transport ships would be operating out of U.S. ports, that all fuel, stores, supplies, overhead costs and insurance premiums would be borne under U.S. market prices. The user may change these assumptions by altering the value of the corresponding cost component sensitivity factors (TRSF).

The slurry system cost is completely invariant as to crew or shipyard origin.

The maintenance and repair costs, however, are implicitly dependent upon the origin of the ship. Since "M&R" is a function of ship capital cost which is a function of where the ship was built, the "M&R" cost for the ship will be different for same size ships of different national origin. The user can also change this assumption using the corresponding sensitivity factor.

The lay-up cost is calculated as the sum of a fraction of each of the component operating costs. For example, that part of the labor costs that would be charged to lay-up costs in a lay-up year would be one tenth of the normal labor cost. In the case of maintenance and repair, the total amount would be charged to lay-up costs. It must be realized that the lay-up cost is only used when the program encounters a lay-up year.

The total operating cost for the transportation sector is the sum of the operating costs for all the ships used in the transportation system.

The variables unique to this section are the speed of the transports, the limiting size of the transport vessel due to port depths, the slurry system cost, the number of mineships, the size of the mineships and the buffering factor used in the accumulation constraints.

The speed and the buffer factor should only be changed (if they are changed at all) over a fairly restricted range and therefore would not be expected to have much effect on the system cost. Likewise, the slurry system cost is at least of an order of magnitude less than the total transport sector capital costs. Therefore, changes in the slurry system would not have much effect on the total cost of the system. The number of mineships, the size of the mineships and the limiting size of the transport ships (particularly when one considers Gulf Coast ports) can have a large effect on the system determination as well as the cost of the system.

D. Processing

The processing sector of the deep ocean mining study model includes all operations from the arrival of the ore at the port facility up to, and including, the disposal of the waste products of the processing plant. The sector is divided into five sub-sectors in the model, and these are further divided into 24 different cost modules. The structure of the sector is shown in Figure III-8. Refer to Appendix D for details.

The model of the processing sector is developed to allow the use of different processing systems. For the purpose of this report, a reduction roast and ammonia leaching system has

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Figure III-8
Structure of the Processing Sector

- Total Processing Investment
  - Equipment
    - Material Preparation
    - Dry & Reduce
    - Leach & Wash
    - Ion Exchange
    - Electrowinning
    - Reagent Recovery
  - Utilities
    - Gasification
    - Power Plant
    - Power Distribution
    - Steam Plant
    - Steam Distribution
    - Cooling Tower
  - Site Development
    - Port Cost
      - Wharf
      - Shore Facilities
      - Land
    - Development
      - Storage Cost
      - Yard Cost
    - Transport
      - Rail Transport
      - Slurry Transport
    - Land
      - Land Purchase
      - Land Preparation
  - Buildings
    - Buildings
  - Waste Disposal
    - Waste Transport
    - Land Purchase

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been used. This system is based, in part, on a system described by engineers at Kennecott Copper Corporation's Ledgemont Laboratory. In this system, the nodules are first crushed to a diameter of 3/8 inch and are dried in a fluid bed dryer. They are then ground to a diameter of 50 microns and heated in a fluid bed furnace to reduce the metal oxides to pure metal. The reduced ore is then fed into a series of mixing vessels and thickeners that run counter to the flow of the leaching solution. Air is injected into the mixing vessels to oxidize the metals into soluble ammonia complexes. The pregnant leach liquor is then passed through a series of liquid ion exchange (LIX) columns to separate the nickel, copper, and cobalt and to send them to electrowinning tanks where the pure metals are recovered. The leach solution, stripped of metal values, is recycled and the tailings from the final thickener are sent to a steam stripping tower to recover ammonia and carbon dioxide. The data required to describe this sytem are further developed in Appendix D. They comprise a list of the major items of processing equipment, factors that describe the capital cost of each item, and the specific energy and material consumption of each item. Also, the process is divided into major sub-groups to determine the labor requirements of the system.

1. Capital Cost Estimation

The capital costs of the sub-sectors of the processing sector are determined from the installed cost of the sum of the components of the sub-sector. Also included in the sub-sector costs are the portion of the project indirect costs and the engineering and contingency fees.

The process equipment required by the plant is described in detail in Appendix D. This equipment only covers the capital investment that describes the specific recovery process being examined. Materials requirements of the process equipment are used in the model to determine the utilities requirements of the plant. Steam and synthetic gas required by the plant are generated within the process plant. Electric power may be generated within the plant up to a maximum amount, beyond which all power is purchased from commercial power plants.

Site development costs include all preparation of the land for the construction and operation of the plant. Dredging and pier facilities, as well as temporary nodule storage, are included at a site on the coast, and slurry transport is used to carry the nodules from port to the plant. All other materials (primarily coal, limestone, lime, and reagents) arrive at the plant by rail. These materials are stored at the plant with a thirty day buffer, so a considerable area is dedicated to the storage of nodules and other materials, and these costs are included in the model.

The cost of the buildings used in the processing plant are estimated as a fraction of the capital cost of the process equipment.

The fifth sub-sector of the processing sector is concerned with the disposal of the tailings of the processing plant. These tailings are composed of the materials of the nodules after the valuable metals are removed. The natural porosity of the nodules, the small grain size of the particles after processing, and the high water content result in a waste that requires a large area of land in an area where the wastes can be contained and separated from the surrounding environment. The capital investment in the waste disposal sub-sector includes purchase of sufficient land on which to dispose of all wastes produced during the entire life of the project, as well as land for the right of way for a buried slurry pipeline connecting the plant with the disposal area. The remainder of the sub-sector cost is accounted for by the cost of the pipeline itself. The costs of preparing the land for the disposal of wastes are imposed during the operating life of the project and are included under the operating costs of the processing sector.

2. Operating Cost Estimation

As in the mining and transportation sectors, the operating costs of the processing sector are grouped into energy, labor, materials, fixed and miscellaneous costs. The components of each of these groups of costs are shown in Figure III-9, and they are discussed in general in this chapter, with greater detail appearing in Appendix D.

Figure III-9
Operating Cost Structure in the Processing Sector

Component	Cost Group	Total
Purchased Electric Power Coal	Energy	Processing Sector Operating Cost
Direct Labor Payroll Overhead Maintenance Labor Indirect Costs	Labor	
Chemicals Operating Supplies Maintenance Materials	Materials	
State Taxes Insurance	Fixed	
Waste Disposal Preparation Slurry Pipeline Operation	Miscellaneous	

The cost of energy includes the cost of electricity purchased from power companies and the cost of coal that is consumed in the operation of the plant. Coal is used to produce a low BTU gas for the drying and reduction of nodules, to produce steam that is used in the recovery of ammonia from the tailings, and to produce electric power that supplements the power purchased from commercial sources. The requirements of electricity, steam, and synthetic gas are determined from the characteristics of the metallurgical process that is used in the model. The details of the computer model, and of the values of fuel and power consumption for the ammonia process, are described in Appendix D.

The cost of labor includes the direct cost of operating labor and supervising, as well as the cost of salary overhead. The labor component of maintenance costs are included, as are indirect operating costs of the processing plant that are proportional to the cost of direct labor in the plant.

The cost of materials includes all chemicals used by the processing equipment. The fraction of maintenance cost that is used for materials is also included. The third element of materials cost is the cost of general operating supplies used in the operation of the processing sector.

Fixed costs are the costs that are proportional to the capital investment in the processing sector. Two categories of fixed cost are considered: state and local taxes, and plant insurance.

The miscellaneous cost group is composed of operating costs that are incurred outside of the perimeter of the processing plant. Two costs are included in this group: preparation of the waste disposal area and operation of slurry pipelines. The cost associated with the waste disposal sub-sector is the annual expense of grading, excavating, and lining the tailings ponds needed to dispose of the wastes produced.

during the year's operation. The transportation cost is composed of the operating cost of two slurry pipelines: one operating between the port facility and the processing plant, and the second between the plant and the waste disposal area.

E. Financial Analysis

The second major part of the model integrates the cost information, developed in the preceding sections, with the revenues expected over the anticipated life of the representative first generation ocean mining operation described above. This integration, incorporating factors such as major activity phasing, investment scheduling, production start-up, debt financing and annual tax liability, permits the model to project annual net cash flows.

From evaluation of these annual net cash flows over the specified project life, the economic return of the ocean mining operation can be estimated using various standard financial measures. For this study, three measures of profitability are calculated: net present value, internal rate of return, and simple payback.

In the discussion which follows, a detailed explanation of annual net cash flow determination is presented, the major factors listed above and their relevance to the project identified, and the profitability measures explained.

1. Project Scheduling

The first task is the identification of the major activity phases of the project and their scheduling on a project timeline. In the model, four major periods are used to define project life. They are:

a) the pre-investment period, during which major research and development activity and significant minesite prospecting surveys are started;

b) the investment period, when the mining and the transportation equipment are procured, the processing plant constructed and detailed minesite exploration indicated;

c) the production period, which includes project start-up; and,

d) the total delays period, which represents the sum of all anticipated delays which might occur during the project's life.

The lifetime of the entire operation is the sum of these periods. Other important times during the project life are related to these four periods. Summarized in Figure III-10, they include:

a) the exploration period, during which a detailed mine plan is developed for a selected minesite;

b) the amortization period during which the project debt is repaid; and,

c) the depreciation period, during which the costs of various tangible assets used in the project are apportioned, primarily for tax purposes, over their defined economic lives.

As noted earlier, various delays may occur which can significantly affect project profitability. The model can take such delays into account, as will be discussed in section 4 below.

2. Escalation

Escalation in economic analysis is defined as the persistent rise in prices of specific commodities, goods, and services due to a combination of inflation, supply and demand interactions, and changes in technology; inflation, a major component of escalation, denotes the general rise in prices not accompanied by an offsetting rise in productivity.[1] The model has the capability of performing profitability analyses in terms of constant purchasing power (unescalated) dollars (hereafter called constant dollars) or current (escalated) dollars. This choice is left to the operator of the model. If the analysis is to be made in terms of current dollars, the user may define discrete annual escalation indices for metal revenues, capital investments, operating costs, and the project discount factor. In this study, constant dollars are used in the baseline and subsequent comparative evaluations. The effect of uniform

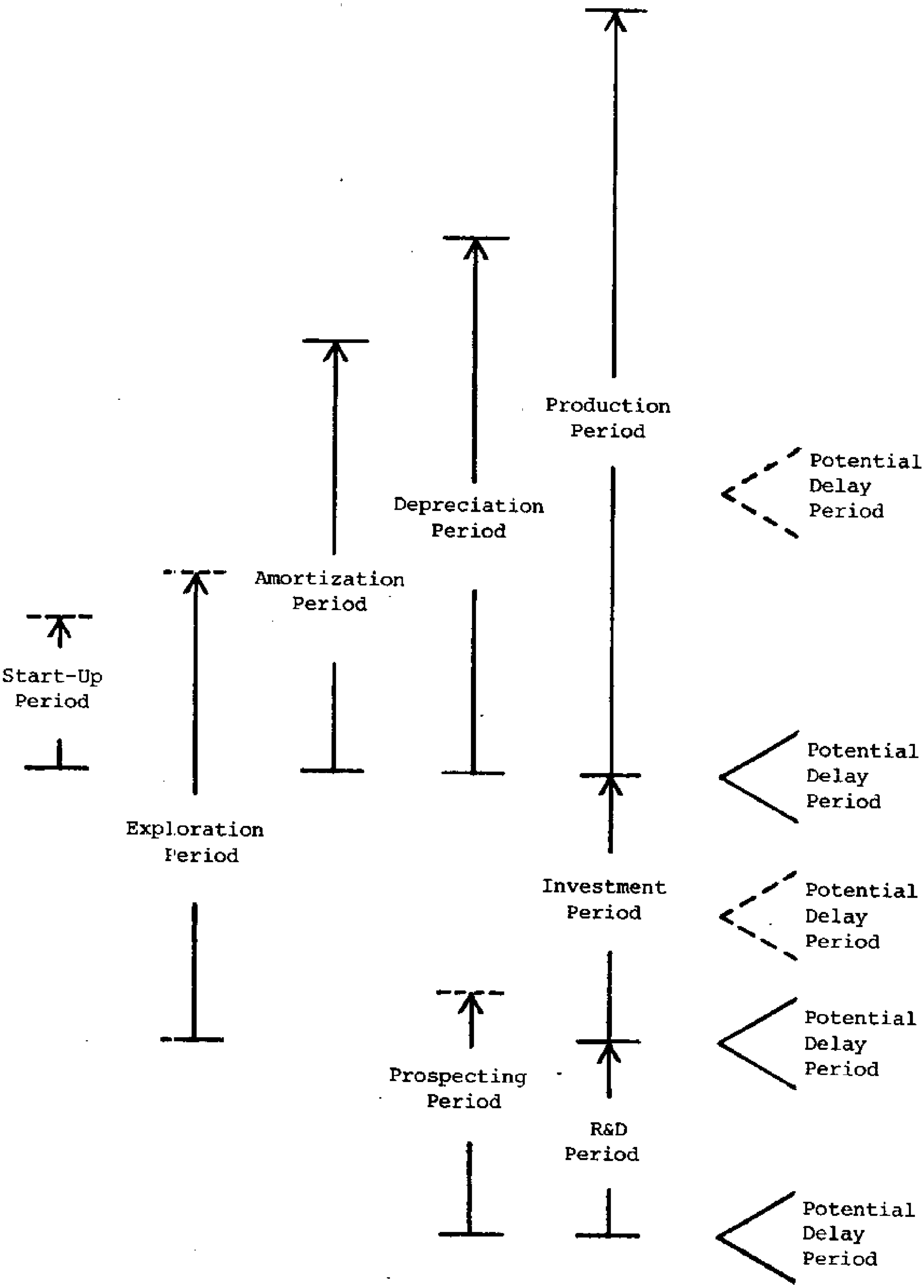


Figure III-10
Project Timeline

escalation is evaluated however, to confirm that escalation is properly treated within the model. (See Chapter VI, section E 3.)

3. Annual Net Cash Flow Estimation

Net cash flow is defined as the net flow of dollars into or out of a proposed project and is equal to the algebraic sum of all cash receipts, investment outlays and project expenses, whether cash or non-cash in nature.[2] In the model, the cash components are the annual gross revenues, the annual capital investment, total costs and the annual tax payment. Figure III-11 illustrates how these various cash flow components interrelate and identifies those non-cash expenses of depreciation, depletion, tax loss carry forward and investment credit which affect annual net cash flow. These components are discussed below in detail.

a) Gross Revenues

Gross revenues are the cash receipts from the sale of the minerals recovered by processing the nodules. They are determined by the annual level of nodule production, the average mineral composition of the recovered nodules, the recovery efficiency of the metallurgical processing plant and the estimated market price of the recovered metallic minerals in a marketable form. During the operating period, the level of annual nodule production is equal to the annual rate of ore production defined earlier. Prior to the production period it is, of course, zero. Using the average nodule composition and the plant recovery efficiencies for the minerals, the model calculates the annual production yields for nickel, copper, cobalt and other metals, as specified by the model's operator. It is assumed that the annual yield of each metal is sold through long term contracts. Using long-run average constant dollar market prices, the annual revenues for each metal are calculated and then summed to give total annual gross revenues.

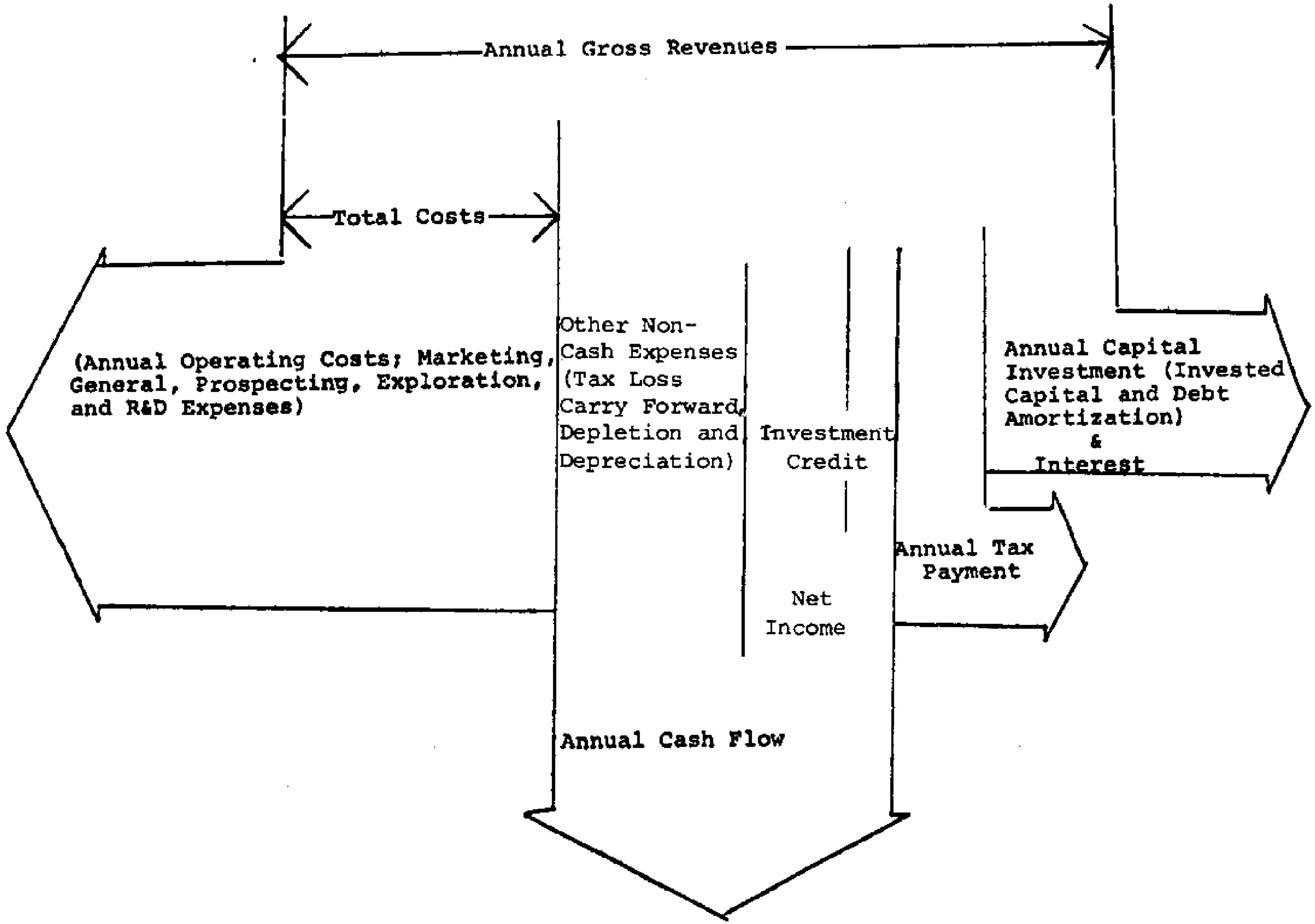


Figure III-11, Determination of Annual Cash Flow

b) Annual Capital Investment

The annual capital investment is that portion of the total required project capital investment which is expended during each year of the project's investment period. If debt financing, to be discussed below, is used, the annual capital investment represents the equity capital expended during each year of the project's investment period and/or principal repayment during the amortization period. The magnitude of any one year's expenditures is determined by a capital allocation factor, defined by the model operator. Naturally, the sum of the individual capital allocation factors for the entire investment period must equal unity.

i) Debt Financing. There are, in general, three possible sources of funds for financing large, technologically sophisticated projects such as ocean mining. They are:

-- financing through ownership, or equity, funds;
-- financing through borrowed, or debt, funds; and,
-- financing through a combination of the two.[3]

(Frequently, another source of funds is long term leasing.)

Intermediate term loans of the type assumed here usually have a maturity (total repayment period) of more than one year and may extend up to and including ten years. Also, they will have an interest rate which can be fixed for the life of the loan or which can vary, being proportional to the average rate of interest at which the lending banks may borrow funds from a Federal Reserve Bank.[4]

In the model, the loan maturity, the accompanying interest rate, and the manner of repayment may be defined by the operator. For this study, a loan period of ten years with an interest rate of 10% has been used.[5]

ii) Restrictive Covenants. Frequently, term loans will have restrictive provisions placed on the borrower by the lender to protect the latter for the duration of the loan. Typical provisions, or covenants, include restrictions on the maximum amount of additional debt the borrower may assume and the periodic submission of financial statements to the lender.[6] In the model, two such covenants are available to the operator.

The first covenant is that the maximum debt allowed is that which can be serviced using 67% of the debt free cash flow. This is equivalent to the specification of a minimum level of working capital which the operation must maintain, defined as a percentage of the unleveraged (non-debt bearing) average annual after-tax cash flow and, in this study, is 33%.

The second covenant available to the operator is specification of the maximum debt-equity ratio the project may have. This limit controls the total amount of debt the project may incur regardless of the number of sources or the project debt servicing capacity. For the baseline study, the specified permissible debt-equity ratio is 1:1. That is, the project incorporates 50% debt in its capital structure.[7] However, the model is used to analyze other levels of debt and the results are presented in Chapter VI.

iii) Repayment. The final relevant feature of a term loan is the manner in which it is repaid. Customarily, term loans are repayable in one of two different methods, as designated by the lender. One method requires loan retirement in equal installments, with a declining portion of the outstanding payments serving to cover the interest charges of the loan[8] (this type of repayment plan is characteristic of bank mortgages to individuals for purchase of real estate). Alternately, term loans can be repaid in equal principal installments with interest payable on the unpaid principal balance.[9] This, of course, results in higher interest payments in the early years of loan retirement. The yearly repayment of the principal, or amortization, is considered annual capital investment during the amortization period. In the baseline study, the former method is used.

Again, as with revenues, the annual capital investments may be expressed in constant dollars or current dollars at the discretion of the model's operator.

Appendix E provides further details.

c) Total Costs

Total costs include the annual operating costs, the marketing and general expenses, and the annual outlays for prospecting, exploration, research and development.

The annual operating costs are the sum of those operating costs in the cost estimation section of the model which apply to the production period of project operations. To provide working capital for operations, the annual operating expenses are increased in the first year of production by an operator defined percentage. In this report, it is assumed that working capital equivalent to two months operating costs (17%) is sufficient. As is customary in this type of analysis, the operating expenses of the final year of production are reduced by the same amount to reflect recovery of this working capital at the end of the project's life.[10]

Marketing and general expenses are assumed to be 3% of annual gross revenues.[11]

Prospecting and R&D expenditures are each defined and entered into the program by the model operator. The model computes the annual amount by allocating each total expenditure evenly over its respective period within the operation.

As noted earlier, the project's exploration cost is computed by the model based upon the estimated minesite size necessary to fulfill the required nodule production rate over the project's specified production period. As with R&D and prospecting expenditures, the model then evenly allocates the total exploration expenditure over the defined exploration period to obtain the annual exploration expense. In some ocean mining operations, exploration or R&D activities may continue into the commercial production phase. In the present model, only the exploration phase has the capacity for the operator to vary the years into the operational period. These costs can include continuing minesite development costs.

The model has the capability of either expensing the annual expenditures for R&D and exploration or capitalizing them and, following commencement of operations, recovering them through apportionment over 60 months and the period of production, respectively.[12] In the baseline analysis, the former option has been used and, therefore, these annual expenses are included in total costs.

As noted above, total costs may be specified either in constant or current dollars.

d) Annual Federal Income Tax Payments

The typical taxpayer will use any flexibility provided in the IRS Code to maximize the present worth of his operation.[13] Flexibility results from various means of expensing capital investment expenditures and from the use of various tax credits such as interest payment deductions, tax loss carry back/carry forward, depletion allowance and investment credit. In Figure III-12 the structure presented in Figure III-11 is reordered so that the tax determination steps may be seen in greater detail.

The starting point for the determination of the annual tax payment is the gross profit, or gross margin, of the operation, defined as gross revenues less total costs. From this sum the annual depreciation expense is subtracted.

i) Depreciation. Depreciation is defined as the accounting procedure used to distribute the cost of a tangible capital asset, less salvage (if any), over the estimated useful life of that asset in a systematic and rational manner.[14] The Internal Revenue Service requires that, in order to depreciate

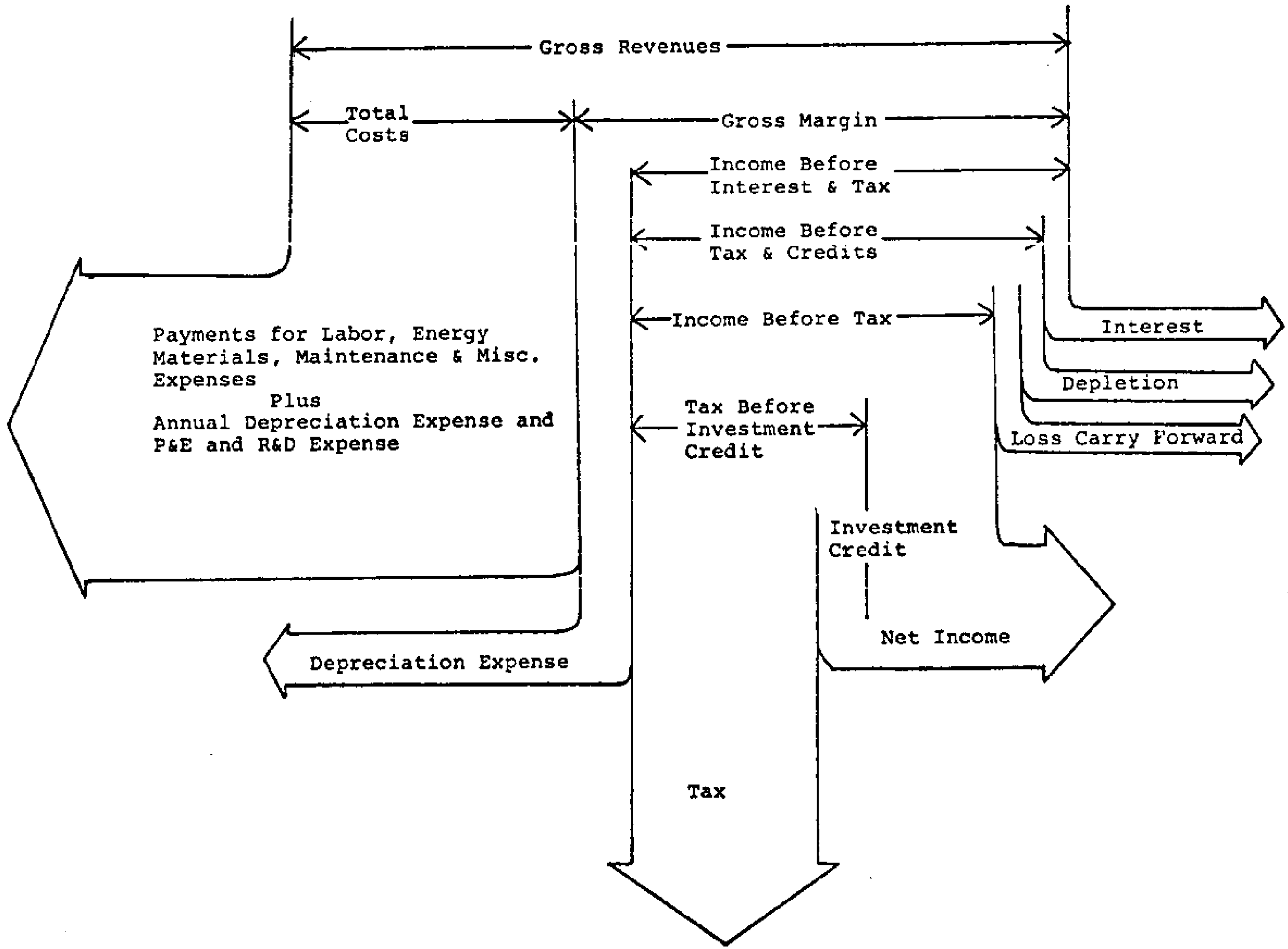


Figure III-12

Determination of Annual Tax Liability

an asset, it must have a useful life of more than one year.[15] The IRS also suggests use of one of three generally accepted methods:

-- Straight-line;

-- Declining-balance; or,

-- Sum of the years' digits.[16]

Straight-Line Depreciation. The straight-line method is the simplest for computing depreciation. Under this method, the cost of the asset, less its salvage value, is deducted in equal amounts annually over the period of its estimated useful life.[17]

Declining-Balance Method. The declining-balance method of depreciation accelerates the rate at which a taxpayer may expense the asset, thus resulting in a higher cash flow in the early years of operation. Currently, the IRS allows a taxpayer, under some circumstances, to use a rate up to twice that allowed under the straight-line method. This rate may be applied annually to the unrecovered portion of the asset's cost. However, the asset may not be depreciated below its reasonable salvage value.[18] If the asset has a useful life of at least three years or is real property acquired prior to July 24, 1969, twice (200%) the straight-line rate may be used. If the asset is used, or is more recently acquired real property which is new, again with a useful life of at least three years, the maximum allowable rate is one and one-half (150%) times the straight-line rate.[19] However, if the asset is used real property, e.g., buildings, acquired after July 24, 1969, the depreciation expense allowed cannot exceed the amount computed under the straight-line method.[20]

Under the declining-balance method, the taxpayer may change to the straight-line method at any time during the asset's depreciation period. This permits the taxpayer to fully recover the fraction of the asset's depreciable cost which remains outstanding under the declining-balance method. The IRS does not require prior consent for this change.[21]

Sum-of-Years' Digits. The sum-of-years' digits method is also an accelerated method which permits an earlier recovery of an asset's adjusted cost (i.e., net of salvage value) and results in higher initial cash flows.[22]

In the model, all three methods of depreciation are available to the operator. If specified, the declining balance method will convert to the straight-line method when the latter is more advantageous. The series of instructions to calculate annual depreciation under any of the above methods is contained in a subroutine of the main computer program. The description of this subroutine and the instructions for its use are given in Appendix E.

ii) Interest. Interest is defined by the IRS as the compensation allowed by law or fixed by parties for the use of money and is an allowable business expense for purposes of computing taxes. All interest paid during the tax year is fully deductible provided it is on an indebtedness under which [the miner] has a valid obligation to pay a fixed or determinable sum of money.[23]

There will be no interest deduction unless some level of debt is specified in the project's capital structure. If debt funding is used, the annual interest charge is computed as part of the repayment schedule. Subtraction of this annual expense from Income before Interest and Tax gives Income before Tax and Credits.

iii) Depletion. Depletion to a miner is the reduction of the mineral-in-place resulting from the 'mining out' of an ore body.[24] The U.S. Tax Code permits mineral producers to write off this reduction in value of the mineral resource via the depletion allowance.[25] Thus, depletion is to the owner of a mineral deposit what depreciation is to the owner of a capital asset.[26] Guidelines for the utilization of the allowance are contained in Internal Revenue Service Regulations §§1.611-1.614; the IRS also publishes updated guidelines annually.[27]

The availability of the depletion allowance for deep ocean mining will probably, for reasons discussed in Appendix F, be a policy question to be decided by deep ocean mining legislation if and when such is enacted. In the baseline study, a 14% 'metal mines' allowance was included. In Chapter VI, the impacts of having no depletion allowance and of having a 22%/15% 'U.S. deposit' allowance are examined. In none of the three cases has the value of the transportation sector been included in the allowance base on the grounds that current law would require a specific request for its inclusion.

Economic Interest. Percentage depletion allowance is available to a taxpayer who has an economic interest in the mineral(s) in-place. An economic interest is considered to be:

> "any interest which a taxpayer has in a mineral (deposit) that is acquired by investment and, by any form of legal relationship, secures for the taxpayer income, to which he must look for the return of this capital."[28]

In spite of the large expenditures the ocean miner will make for site exploration and development for acquisition of the necessary mining and processing equipment and for annual operations, it is presently unclear in the law whether he will have a qualifying economic interest in the mineral in-place.[29] In the baseline model, it is assumed that appropriate legislation assures the domestic ocean miner of an allowance for depletion of the minesite. The impact of its not being allowed is examined in Chapter VI. The issue is discussed further in Appendix F.

Allowance Determination. There are two methods for determining the depletion allowance, cost or percentage.[30] As specified by IRS Regulations §§1.613-2, the allowable deduction is the higher of the two; normally, percentage depletion will exceed cost depletion, the former having the attractive characteristic of rising as income rises while the latter declines with increased ore reserve declarations and eventually is fully recovered, thereby disappearing.[31] In the model, it is assumed that percentage depletion will always be more favorable and, therefore, it is the only method used.

The applicable guidelines for computing percentage depletion allowance are sufficiently stated within IRS Regulations §§1.613-3(d)(1) to encompass a unique ore such as manganese nodules. These guidelines provide for situations where the "gross income from mining" cannot be readily determined due to the lack of a representative field price for the ore or due to the necessity for additional ore processing to produce the first marketable product. By the Proportionate Profits Method, the miner is able to determine gross income from mining as that percentage of gross sales from the first marketable product which is equivalent to the proportion of the point of sale. This determination is made by the following equation:[32]

$$\frac{\text{Mining Costs}}{\text{Total Costs}} \times \text{Gross Sales} = \text{Gross Income from Mining}$$

<u>Multi-Mineral Ore.</u> If the ore contains two or more minerals subject to differing rates of depletion, the allowable deduction can be computed by taking the allowable percentage of the gross income from each mineral. As with single mineral deposits, the aggregate allowance, when computed in this manner, is subject to a maximum limit of 50% of the net income, before tax and without depletion, resulting from the sale of the minerals.[33]

Subtraction of the computed allowance from Income before Tax and Credits gives Income before Tax Loss Credit.

iv. Tax Loss Credit

If the ocean mining project sustains a net operating loss during the tax year, that loss may be applied as a credit to previous and/or future years' earnings under the loss carry back and carry forward provision.[34] If the loss for any tax year is incurred after 1975, the ocean miner may elect to forego the carry back period.[35] In the model, provision is made to carry any year's operating loss forward as a credit in the seven succeeding years and the carry back option is foregone. Subtraction of this credit for prior years' losses from Income before Tax Loss Credit gives Income before Tax.

v. Other Tax Credits

Other credits available for consideration by the ocean miner include those normally available to any domestic corporation. They are extensive and annual guidelines are published by the IRS to assist in evaluating their applicability.[36] Those having the most relevance to this study are:

-- credit for state and local income tax and real property tax payments;

-- credit for annual business insurance premiums; and,

-- credit for repairs, replacements and improvements.

State and local taxes are applicable to those parts of an ocean mining operation which are located on shore. For the current generation of mining activity, this would be the metallurgical processing plant, described earlier. As shown in Figure III-9 above, these taxes have been computed and included in the fixed costs of the processing sector's operating costs, which have subsequently been included in the project's total costs.

Insurance premiums applicable to the different sectors have been computed and subsequently included in the project's total costs.

Repairs, replacements and improvements also represent potential deductible expenses.

Repairs. Repairs maintain property in an ordinarily efficient operating condition. To the extent repair expenses are routine, they are allocated to the cost of goods sold and reported in total costs as maintenance expenses.

Replacements. Expenditures for replacements of parts of machinery to maintain it in an efficient operating condition are deductible business expenses. In first generation ocean mining operations, replacement of the lift system piping and bottom units at the anticipated yearly rate requires that this expenditure be expensed. As with repairs, these expenses are considered routine and have been included in the mining sector's operating costs.

Improvements. Improvements result from extensive overhaul or replacement and have the effect of increasing the value of property, prolonging its life or making it adaptable to a different use.[37] These expenditures must be considered as capital investment and, therefore, capitalized and recovered through annual depreciation. In the model, it is assumed that the actual productive lives of the various components and facilities will include the designated period of operations and that any minor overhaul expenditures are included in the maintenance costs of the respective sectors and expensed annually. As major fixed assets usually have a service life equal to or greater that the Asset Depreciation Range defined by the IRS, the assumption is acceptable for project analysis.

vi. Investment Credit

Under the current Tax Code, a credit against annual tax liability is provided for qualified investment expenditures made during the tax year. Investment expenditures are qualified for the credit if made to acquire new or used depreciable property considered an integral part of manufacturing, production or extraction operations and having a useful life of at least three years.[38] However, with used property, no more than $100,000 of the cost may be considered in determining credit for any one year. The allowable credit is a percentage of total qualified expenditures and is limited to 50% of the annual tax liability. Under the Tax Reform Act of 1976, the increase in the investment credit percentage from 7% to 10% is continued in effect until January 1, 1981.[39]

When a large investment is made over a period of two years or more, such as in construction of a new facility, the annual progress payments may be treated as qualified investment expenditures.[40] However, those expenditures for building wharves, docks, land and other property related to the production site are <u>not</u> considered qualified.[41] Property in the nature of machinery is the principal type for which expenditures qualify.[42]

The model considers the annual investment as a qualified progress payment and uses the applicable rate in computing the credit. Doing so permits maximum use of the temporary 10% credit. Subtracting the computed credit from Tax before Investment Credit gives the annual tax liability the ocean miner will incur.

viii) <u>Net Income</u>

Net Income is the remainder after the tax liability is subtracted from the Income before Tax and represents the major source of cash inflow from the ocean mining operation.

4. <u>Economic Return Estimation</u>

Evaluating the return to the private sector from a potential ocean mining project is best accomplished using the standard capital budgeting technique of discounting future cash flows resulting from the project. Discounting gives explicit recognition to the fact that time has economic value to an investor and, therefore, that currently received, or present, dollars are worth more than those received in the future.[43]

The two most frequently used methods for discounting cash flows are the net present valuation method and the internal rate of return method. Both are used in the model to measure profitability.

a) Net Present Valuation

The net present valuation method involves finding the present value, when discounted at a chosen rate, of all annual net cash flows from the investment for a designated period of time and summing them to obtain the net present value (NPV), or current worth, of that investment. If the NPV is positive, the project will exceed the defined profitability criteria under the discount rate assumed for the evaluation. Similarly, if the NPV is negative, the project will not satisfy the defined profitability criteria.

Discount Rate. The choice of discount rate is critical to the use of the NPV method. In traditional financial analysis, the discount rate represents the investor's marginal cost of capital, or the opportunity cost of each additional dollar used for capital investment.[44] Frequently, the chosen rate is the weighted average cost of all capital, both debt and equity, adjusted by the investor to reflect the uncertainty associated with both the investment's long run weighted average cost of capital and the anticipated revenue stream.[45]

Each of the various members of the consortia active in ocean mining probably has different criteria for defining its cost of capital and, consequently, the profitability it expects from the project. As noted in Chapter I, the model has been developed to provide U.S. policy decision-makers the capability to examine different issues as they become timely. As with private investors, public decision-makers will also apply differing discount rates. For these reasons, it is desirable to evaluate the expected profitability of the project over a range of discount rates. This feature has been provided in the model and both the range of and increment for discount rate may be arbitrarily defined. For the baseline and subsequent evaluations, the discount rate ranges from 8% to 24% in an increment of 2%.

b) Internal Rate of Return Method

The internal rate of return (IROR) is defined as that discount rate at which the net present value is zero.[46] The same methodology is used to determine both NPV and IROR. The latter calculation, however, is done by iterating over a broader range of discount rate with a smaller increment. In the model, the iteration process starts with a discount rate of zero percent and is successively incremented by .01% until the value of the NPV is calculated to be less than or equal to zero. The discount rate used in that iteration is defined as the IROR.

Differences Between NPV and IROR. From the above discussion it may be seen that the only computational difference between NPV and IROR is the discount rate used. In the former method it is specified while in the latter method, it is calculated. However, the differences are more subtle and affect the interpretation of project profitability.

External conditions which would cause different interpretations of project profitability include:[47]

-- significant differences in the investment costs used when considering alternate scenarios;

-- differences in the timing of project cash flows; and,

-- the recurrence of negative cash flows after the stream initially turns positive such as would occur with significant capital reinvestment.

These characteristics affect the consideration given to reinvestment of the future cash flows. The NPV method explicitly assumes reinvestment at the investor's marginal cost of capital. The IROR method implicitly assumes reinvestment at the computed internal rate of return, which may be unrealistic. In general, most investors, particularly corporations, find the NPV method most useful in profitability evaluations.[48]

c) Payback Period

The private sector frequently complements the determination of NPV and/or IROR with the calculation of a project's payback period.

The payback period is defined as the number of years, following the start of the production period, required to recover an investment from net cash flows and it is frequently interpreted as the period during which the initial investment is at risk.[49] In calculating this period, the economic time value of money and the cash flows received after the payback period are ignored. These characteristics bias this measure of profitability against those investments which do not yield their highest returns until late in the project's life. For these reasons, many investors use the payback method only in connection with one of the discounted cash flow techniques discussed above.[50] The model computes the payout period and measures the results to the nearest tenth of a year.

The detailed description of the computational methodology for each of the above measures is provided in Appendix E.

5. Delays

The life of any major project is usually marked by delays which can occur at any point throughout the project. To recognize these delays, the model has a special phase which is a part of the project's scheduled life span. It is that period of time representing the sum of all anticipated project delays and is integrated into the project schedule as outlined in subsection 1, above.

The model schedules the capital investment and operating expenses over the project's lifetime. In the model, the investment is considered a "normal" one, in that the significant capital expenses occur early in the project's life with the operating expenses following.[51] As such, the operation is divided into the various phases outlined earlier.

Delays can occur at various times and for various reasons. For example, the initial decision to undertake prospecting and exploration and/or research and development may be postponed if the existing economic conditions suggest the project will not bring a satisfactory return, i.e., that it is unlikely to satisfy the investor's profitability criteria. Delay prior to investment of the necessary capital for mining equipment and processing plant construction could also be prompted by economic factors such as a drop in metal prices or severe inflation in construction materials and labor costs.[52]

These same economic influences and/or those resulting, for example, from prolonged labor contract disputes, can create a delay during the investment period.[53] The recent burgeoning requirements of regulatory compliance and the unpredictable occurrence of suits over environmental issues are increasingly creating lengthy delays prior to initiation of operations.[54] Singularly or collectively, these delays are the costliest feature of the "front-end cost syndrome" becoming more prevalent among corporate planners.[55]

Other delays which create problems for large, complex projects are those which result from interruption of on-going operations. Most often resulting from many of the above factors such as union contract disputes and environmental protagonists' confrontations, such delays may have serious impacts upon planned ocean mining operations.[56] Concerns over minesite harrassment, operational constraints imposed by potential future regulatory regimes and similar matters associated with current Law of the Sea negotiations could all eventually materialize as operational delays during the first decade of at-sea operations.[57]

Whatever the cause of the delays, one thing is certain. The impact upon the planned operation will be unfavorable and will result in a lowering of the project's anticipated NPV.

In order to incorporate delay scheduling into the model, the model incorporates the capability to measure the impact of five arbitrarily selected delay periods:

- -- Pre-Research and Development Delay;
- -- Pre-Investment Delay;
- -- Intra-Investment Delay;
- -- Pre-Operation Delay; and,
- -- Intra-Operation Delay.

Key times in the life of the operation have been denoted through the use of the three project phases and the various delays. The beginning of both the prospecting and the research and development periods follow the initial delay period, denoted as the pre-R&D delay. The pre-investment delay period which follows the R&D period ends when investment begins. However, prospecting and/or exploration may continue during this time. During the investment period, there is provision for a delay period of arbitrary length. Following the investment period, there is the post-investment delay period which ends when production commences. The final delay period recognized is that which can occur during production. All delay periods are summarized on the previously referenced project time line, diagrammed in Figure III-10.

Chapter III Notes

1. Stermole, Franklin A., Economic Evaluation and Investment Decision Methods, 1974. Golden: Investment Evaluations Corporation, p. 165.

2. American Association of Cost Engineers, "Cost Engineering Terminology," in Cost Engineers' Notebook, Section AA-4.000, 1971.

3. Eugene L. Grant et al., Principles of Engineering Economy, Sixth Edition, p. 417.

4. J. Fred Weston and Eugene F. Brigham, "Term Loans and Leases," in Management Finance, 5th Edition, p. 475.

5. The interest cost of term loans varies with the size of the loan, the financial condition of the borrower and the source from which the funds are obtained. For large loans to large firms from single sources, the rate will be close to the prime. However, other considerations, such as inflation, risk and borrowing fees influence the effective rate. In this study, it is assumed that both commercial banks and life insurance companies provide the borrowed funds, hence a maximum maturity and a high rate have been assigned to the representative debt to encompass the above factors.

6. Supra note 4, p. 474.

7. The use of these particular covenants follows the suggestions of a senior banking executive offered at a recent NOAA workshop on Deep Ocean Mining.

8. Supra note 4, p. 474.

9. Supra note 7.

10. Supra note 3, p. 165.

11. Kennecott Copper Corporation, 1975 Annual Report.

12. Internal Revenue Service Publication No. 535, Tax Information on Business Expenses, 1977 Edition, p. 10.

13. Supra note 2, Section D-7.800, 1965.

14. Supra note 3, p. 149.

15. Internal Revenue Service Publication No. 534, Tax Information on Depreciation, 1977 Edition, p. 1.

16. Ibid., p. 6.

17. Ibid., p. 6.

18. Ibid., p. 6.

19. Ibid., p. 7.

20. Standard Federal Tax Reporter, 1977, Volume 2, para. 1754C.

21. Supra note 15, p. 7.

22. Supra note 15, p. 7. Under the remaining life version of sum-of-years digits, a different fraction is applied to the assets' adjusted cost to compute annual depreciation. The denominator of the fraction changes each year to a number equal to the total of the digits representing the years of estimated useful life remaining for the property. The numerator of the fraction changes each year to represent the years of useful life remaining at the beginning of the year for which the computation is made. This method may only be used for assets which qualify for the declining balance method at twice the straight-line rate (200%). To change from this method to any other requires the prior written consent of the IRS.

23. Supra note 12.

24. Supra note 3, p. 211.

25. 26 U.S.C.A. 611, Note 1.

26. Standard Federal Tax Reporter, 1977, Volume 5, p. 42007.

27. Supra note 15, pp. 20-22.

28. Regulations §1.611-1(b)(1).

29. Current summaries on the legal environment facing the ocean miner on this and related matters can be found in Northcutt Ely and R. F. Pietrowsky, Jr., "An Opinion Re: International Law Applicable to Ocean Mining," November 14, 1974, Washington, D.C.

30. Regulation §1.613.

31. Thomas J. O'Neil, "The Minerals Depletion Allowance: Its Importance in Nonferrous Metal Mining," in Mining Engineering, October 1974, p. 63.

32. Regulations §1.613-3(d)(4)(ii).

33. Revenue Ruling 76, 1953-1 CB 1976. If net income before allowance for depletion is zero in any year, no depletion credit may be claimed.

34. Internal Revenue Service Publication No. 334, Tax Guide for Small Business, 1971 Edition, p. 83.

35. Ibid., p. 83.

36. Supra note 15. See also Internal Revenue Service Publication No. 542, Corporations and the Federal Income Tax and Publications No. 572, Tax Information on Investment Credit, Current editions.

37. Supra note 3, p. 22.

38. Supra note 36, IRS Publication No. 572, 1977 Edition, p. 1.

39. Ibid., p. 1.

40. Ibid., p. 5.

41. Ibid., p. 2.

42. Ibid., p. 1.

43. Supra note 3, p. 107.

44. Supra note 4, pp. 258-285, particularly p. 260.

45. A detailed analysis of determining the discount rate applicable to mineral recovery project investment valuation is presented to Eli Sani in "The Role of Weighted Average Cost of Capital in Evaluating a Mining Venture" in Mining Engineering, Volume 29, Number 5, (May 1977), pp. 42-46.

46. Supra note 4, p. 267.

47. Ibid., p. 272. Detailed examples are provided by the authors to illustrate the effect of these conditions on profitability calculations.

48. Ibid., p. 274. See also "the meaning of present value" in The Capital Budgeting Decision by Harold Bierman, Jr., and Seymour Smidt (4th Edition, Macmillan, 1975), pp. 69-82.

49. Supra note 4, p. 267.

50. Ibid., p. 267. Also supra note 3, pp. 520-521.

51. J. F. Weston and E. F. Brigham, Managerial Finance, 5th Edition, (Hinsdale, 1975), p. 297.

52. D. S. Webber, "Projects Stifled by Regulatory Red Tape," in Chemical Marketing Reporter, March 7, 1977, pp. 11-14.

53. Wall Street Journal, March 15, 1977, p. 37. The Sunshine Mining Company's Kellogg, Idaho silver mine recently announced the end of a contract dispute strike by 500 workers which started on March 11, 1976.

54. Webber, Ibid.

55. Webber, Ibid.

56. Wall Street Journal, Ibid.

57. J. D. Nyhart, "The Interplay of Law and Technology in Deep Seabed Mining Issues," in Virginia Journal of International Law, Vol. 15, No. 4, Summer 1975, pp. 866-867.

CHAPTER IV. THE INITIAL VALUE OF THE MODEL'S MAIN PARAMETERS

All input variables to the ocean mining model are assigned initial values that represent the conditions of the "baseline" model. The baseline conditions are summarized in the following sections of this chapter as well as by sector in the appropriate appendix. The variables can be easily changed at the will of the operator but the initial values have been chosen to represent, to the greatest extent possible, the current state of the art in mining, transportation, and processing.

The following list of initial values is divided into five groups: Prospecting and Exploration; Mining; Transportation; Processing; and Financial Analysis. The lists include the variable name in capital letters, a description of the variable, and the initial value and units of the variable. In addition, Table IV-1 displays data for each piece of processing equipment used.

A. Initial Values of Input Variables in the Prospecting and Exploration Section

Variable	Description	Value	Units
AAFM	Area of Site Available for Mining	.8	
ABB	Surface Abundance of Nodules on Seafloor	2	lb/ft^2
ARO	Annual Rate of Recovery of Ore	3000000	Dry Short Tons
COLEFF	Collector Efficienty	.65	
EXPLBR	Cost of Labor in Exploration Program	660000	Dollars
MAPCST	Cost of Continuous Mapping Survey	432	$\$/km^2$
PROSCS	Cost of Complete Prospecting Program	1600000	Dollars

Variable	Description	Value	Units
SHRENT	Daily Rental Rate of Research Vessel	5000	\$/day
SOILCS	Cost of Discrete Soil Sampling Survey	97	$\$/km^2$
SWPEFF	Sweep Efficiency	.50	
WNSEF	Water-Nodule Separation Efficiency	1.0	

B. Initial Values of Input Variables in the Mining Sector

Variable	Description	Value	Units
ABB	Surface Abundance of Nodules	2	lb/ft^2
ADMFEE	Administration Expense Fraction	.064	
ARO	Annual Rate of Recovers of Ore	3000000	Dry Short Tons
ASCSTL	Annual Cost of Labor per Mineship	2100000	Dollars
BASMSH	Mineship Cost Equation Multiplier	4550000	Dollars
BUMFAC	Bottom Unit Maintenance Cost Fraction	.05	
BUPY	Number of Bottom Units Replaced per year per ship	2	
CDS	Drag Coefficient of Nodule	.5	
COLEFF	Collector Efficiency	.65	
COLWTH	Collector Width	30	Feet
CPLPR	Price of Single Pipe Coupling	7700	Dollars

Variable	Description	Value	Units
DENS	Density of Pipe Material	485	lb/ft^3
DN	Diameter of Nodule	.125	Feet
DW	Depth of Water at Minesite	18000	Feet
EXPMSH	Mineship Cost Equation Exponent	.39	
FACINS	Pumping Unit Installation Factor	3.4	
FF	Darcy Friction Factor	.013	
NMSH	Number of Mineships in Mining Sector	1	
PEF	Pump Operating Efficiency	.65	
PILF	Pipe String Lifetime	1	Year
PIPTH	Wall Thickness of Lift Pipe	.04	Feet
PMMFAC	Pumping Unit Maintenance Cost Fraction	.05	
PMPDTH	Submergence Depth of Pumping Unit	3000	Feet
PPRICE	Price of Power at Sea	.03	$/HP-HR
RHON	Density of Nodules	128	lb/ft^3
RHOW	Density of Seawater	64	lb/ft^3
SBUCST	Cost of Single Bottom Unit	1500000	Dollars
SEF	Ship Propulsion System Efficiency	.65	
SHMFAC	Ship Maintenance Cost Fraction	.05	
STCST	Cost of Fabricated Pipe	1	$/lb

Variable	Description	Value	Units
WDS	Work Day at Sea	24	Hours
WNSEF	Fraction of Nodules Recovered from Lift	1	
WYS	Work Year at Sea	300	Days

C. Initial Values of Input Variables in the Transportation Section

Variable	Description	Value	Units
BUFCAP	Maximum Mineship Capacity	60	1000 DWT
CREW	Foreign or Domestic Crew Costs	1	Foreign
LIMIT	Limiting Size for Given Port	80	1000 DWT
NMSH	Number of Mineships	1	
OWDIS	One Way Distance to Port	1750	Nautical Miles
SLURRY	Slurry System Cost	1.8	Million Dollars
SPD	Speed	15	Knots
YARD	Foreign or Domestic Ship Yard Costs	1	Foreign

D. Initial Values of Input Variables in the Processing Sector

Variable	Description	Value	Units
ARO	Annual Rate of Recovery of Ore	3000000	Dry Short Tons
ARST	Area of Processing Plant Site	200	Acres
BFAC	Buildings Uost Estimation Factor	.1	
COALPR	Price of Coal Delivered to Plant	15	$/Ton

Variable	Description	Value	Units
COMP	Nodule Composition		
	Nickel	1.5	Percent
	Copper	1.3	Percent
	Cobalt	0.24	Percent
	Manganese	26.9	Percent
CONFEE	Contingency Fee	.15	
DIS1	Distance from Port to Processing Plant	5	Miles
DIS2	Distance from Plant to Waste Disposal Area	25	Miles
DIS3	Distance from Plant to Rail Transportation	5	Miles
ENGFEE	Engineering Fee	.05	
FID	Construction Indirect Cost Factor	1.4	
KOPS	Length of Operating Life of Mining Project	25	Years
LAND1	Price of Land at Waste Disposal Site	2000	$/Acre
LAND2	Price of Land at Plant Site	10000	$/Acre
LAND3	Price of Land at Port Facility	20000	$/Acre
LAND4	Price of Land between Port and Plant	2000	$/Acre
LAND5	Price of Land along Waste Disposal Pipeline	1000	$/Acre
PAYOHD	Overhead on Operating Labor and Supervision	.25	
PINSRT	Insurance Rate on Processing Plant	.01	
PORTAR	Area of Port Facility	10	Acres
POWLIM	Upper Limit on Power Plant Capacity	25100	KW

Variable	Description	Value	Units
PP	Price of Commercial Electric Power	.03	Dollars/KW-HR
PPEFF	Power Plant Energy Conversion Efficiency	.33	
PRLNR	Price of Liner for Waste Tailings Ponds	2	$\$/Yd^2$
PRPCST	Cost of Pre-construction Land Preparation	4.39	$\$/Yd^2$
RE	Metal Recovery Efficiency		
	Nickel	95.	Percent
	Copper	95.	Percent
	Cobalt	60.	Percent
	Manganese	0.	Percent
RLCMP	Cost of Rail Facilities	234000	$/Mile
SCPM	Cost of Slurry Pipeline	250000	$/Mile
SGEXP	Cost Equation Exponent for Syn-Gas Plant	.8	
SHRCST	Cost of Shore-side Facilities at Port	664850	Dollars
SLRYOP	Operating Cost of Slurry Pipeline	.01	$/Ton-Mile
STMEFF	Energy Conversion Efficiency of Steam Plant	.9	
STXRT	State Tax Rate on Processing Sector	.01	
UPKF	Maintenance Cost Estimating Factor	.04	
WAGE	Operating Labor Wage	8	$/Hour
WD	Work Day of Processing Sector	24	Hours
WRFCST	Cost of Wharf Facility	1250000	Dollars

Variable	Description	Value	Units
WY	Work Year of Processing	300	Days
YRDCST	Cost of Yard Improvement at Plant	558600	Dollars

E. Initial Values of Input Variables in the Financial Analysis Section

Variable	Description	Value	Units
AP	'A priori' Probability	5*.1 5*.075 5*.05 35*0.0	
BLDR	Lower Limit on Discount Rate Range	8	Percent
CAPFC	Capital Allocation Factor	3*.3333334 7*0.	
CCSF	Capital Cost Sensitivity Factor	30*1.	
DBTI	Debt Increment	16.7	Percent
DERMAX	Maximum Allowed Debt Equity Ratio	1:1	
DLY	Delay Period Lengths	5*0	Years
DPLA	Ore Depletion Allowance	0	Percent
DRI	Discount Rate Increment	2	Percent
DSCFF	Debt Service Cash Flow Factor	0.67	
IG	Investment Guarantee Selector	0	
KDP	Group Depreciation Period Mining Equipment Transport Equipment Process Equipment	 10 18 14	 Years Years Years

Variable	Description	Value	Units
KDPMAX	Maximum Depreciation Period	20	Years
KE	Exploration Period Startup	2	Years
KINVST	Investment Period	3	Years
KLN	Amortization Period	10	Years
KPE	Exploration Period	2	Years
KPP	Prospecting Period	2	Years
KOPS	Operating Period	25	Years
KOP1	Initial Operating Period	0	Years
KP1	Preinvestment Period	2	Years
KRD	Research & Development Period	2	Years
KSU	Start Up Period	0	Years
KV1	Initial Investment Period	0	Years
LOAN	Loan Repayment Method	0	
METH	Method of Depreciation	2	
MORTZ	Amortization Selector	0	
MPPD	Depletion Allowance Method Selector	0	
MV	Metal Prices		
	Nickel	2.00	$/lb
	Copper	0.71	$/lb
	Cobalt	4.00	$/lb
N	Number of Sensitivity Analyses	0	
NG	Number of Groups in Each Sector	6	
NGL	Graph Format Control	0	

Variable	Description	Value	Units
NOM	Number of Minerals Recovered	3	
NRUNS	Number of Runs	1	
NS	Number of Sectors in Cost Estimation	5	
NSA	Sensitivity Analysis Selector	0	
NTSA	Sensitivity Analysis Designator	0	
NU	New or Used Assets Designator	19*0,1,10*0	
OCSF	Operating Cost Sensitivity Factor	30*1.	
OOG	Graph Selector	0	
001	Output Format Control	1	
PCDPL	Mineral Percentage Depletion		
	Nickel	14	Percent
	Copper	14	Percent
	Cobalt	14	Percent
PSV	Project Salvage Value	0	Percent
RDX	Research & Development Expense	50	Million Dollars
SCEF	Start Up Period Cost Efficiency	5*1.	
SDR	Social Discount Rate	10	Percent
SLDR	Specified Discount Rate for Study	0	Percent
SREF	Start Up Period Recovery Efficiency	5*1.	
STXRT	State Tax Rate	1	Percent

Variable	Description	Value	Units
SVNP	Salvage Value of New Project	50	Percent
SVP	Sector Salvage Value	30*0.	Percent
TLDR	Upper Limit on Discount Rate Range	24	Percent
TR	Tax Rate	48	Percent
USFRAC	Fraction of U.S. Investment	1.	
V	Sensitized Variable Designator	0	
VLO	Value of Landed Ore	0	Dollars
W	Sensitized Variable Descriptor	Blank	
WRD	Recovered Mineral Descriptor	Nickel Copper Cobalt	
WRD2	Recovered Mineral Symbol	Ni Cu Co	
XICDT	Investment Credit, Post 1980	7	Percent
XIF	Escalation Index		
	Revenues	0	Percent
	Investment	0	Percent
	Costs	0	Percent
	Discount Rate	0	Percent
XIR	Term Loan Interest Rate	10	Percent
XTICDT	Temporary Investment Credit	10	Percent
YEAR1	First Year of Project Activity	1976	

Table IV-1, Processing System Data for the Deep Ocean Mining Study Model

Number of items of processing equipment: NN = 11

Number of processing sub-groups: NSG = 6

	I	TYPE(I)	BASE(I)	EXP(I)	P(I)	F(I)	S(I)	CH(I)	CW(I)
Crusher	1	0	170.23	1.22	4.77	0.0	0.0	0.0	0.0
Dryer	2	0	205800.0	.72	8.95	1.5	0.0	0.0	0.0
Grinder	3	0	13602.0	.70	4.77	0.0	0.0	0.0	0.0
Furnace	4	0	339337.0	.72	17.9	2.5	0.0	0.0	0.0
Mixers	5	0	107362.0	.81	6.26	0.0	0.0	0.5	0.0
Pumps, Cent.	6	0	9343.0	.34	.23	0.0	0.0	0.0	0.0
Pumps, Diaph.	7	0	4323.0	.50	.23	0.0	0.0	0.0	0.0
Thickeners	8	0	151798.0	.6	.19	0.0	0.0	0.5	200.0
LIX Circuit	9	1	7568000.0	.6	11.11	0.0	0.0	13.47	5780.0
Electrowinning	10	1	1208500.0	1.0	2400.0	0.0	0.0	0.0	26600.0
Stripping Tower	11	0	311331.0	.71	0.0	0.0	1.0	0.0	4000.0

Note: See Appendix D, sections IVA and B, pp. D19 to D24, for further identification of these data.

CHAPTER V. COST ESTIMATION RESULTS

A. Introduction

The cost estimation results of the baseline case described in sections III A-D are presented in section B of this chapter. These results are calculated for the initial values given in Chapter IV and Appendices A-D. The effects on costs of changes in values of nearly sixty individual input variables are presented in section C. Section D examines the effects on costs of several changes in basic design assumptions used in the model's mining, transportation and processing systems. These design changes, which have the effect of increasing costs, represent rational alternatives to those used in the study.

B. Baseline Cost Results

Costs are grouped into four types: research and development, prospecting and exploration, capital, and operating expenses. The last three sets of costs are based on the values assigned to the input variables in Chapter IV. Since research and development expenses are, in this study, expressed as a single cost representing the entire sum of the R. and D. program, the cost is entered in the financial analysis section described in section III E and Appendix E of the model. The cost figure is presented in this chapter, however, in order to provide a full picture of the costs which are typically expended in the early phases of an ocean mining project.

1. Summary of Estimated Capital and Operating Expenses Prior to Commencing Commercial Operation and Annual Operating Expenses

The following table summarizes the four types of costs estimated for the baseline model:

Table V-1

Summary of Cost Estimates

(in millions of dollars)

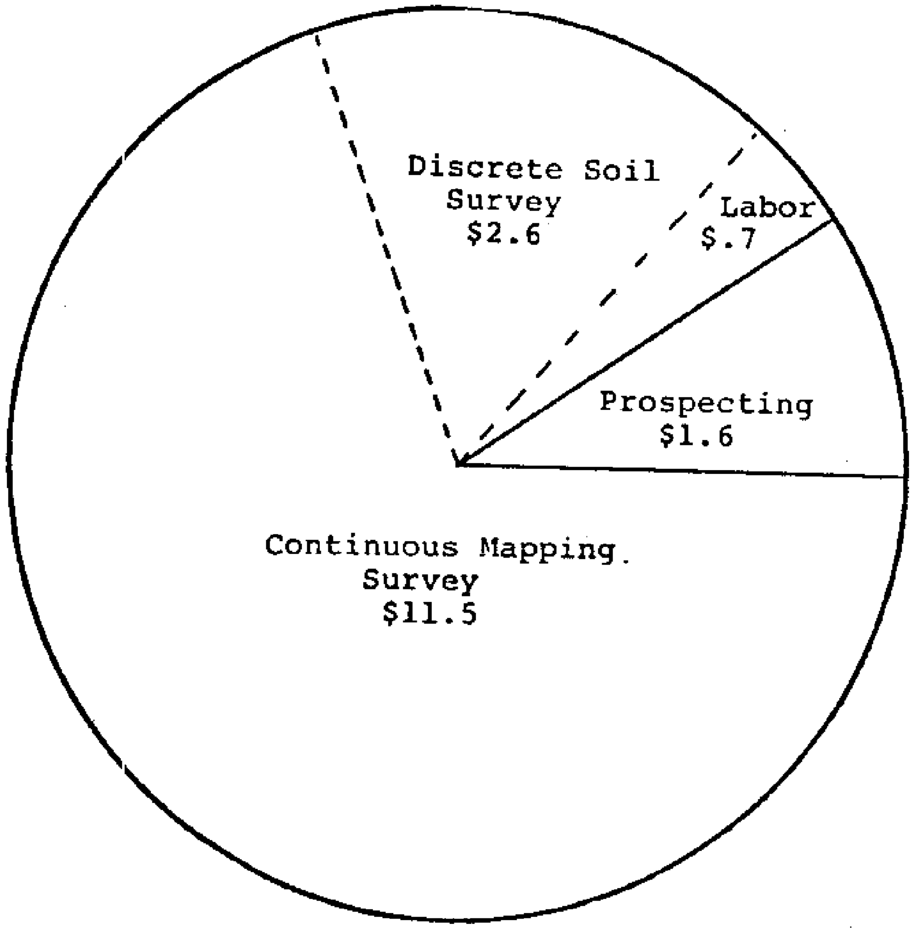
Research and Development (See Chapters III and IV)	50.00
Prospecting and Exploration	16.40
Capital Investment	493.05
Total Capital and Operating Expenses Prior to Commencing Commercial Recovery	559.45
Estimated Annual Operating Costs	100.50

Details of the costs are presented in subsections 2 through 4.

2. Prospecting and Exploration Costs

Prospecting and exploration costs of $16.4 million are composed of four expenses: prospecting cost, exploration labor costs for the research team, the cost of conducting the mapping survey, and the cost of conducting the survey for discrete samples of nodules and soil. These costs are illustrated in Figure V-1. They are reported in Table V-2, Pre-Investment and Investment Expenses in the Baseline Model, pp. 5 - 7, which lists the major estimated costs incurred by the hypothetical project prior to commencing commercial recovery.

Figure V-1
Prospecting and Exploration Costs: $16.4 million
(in millions of dollars)



These prospecting and exploration costs, described in section III A, are allocated over time and used in the financial analysis section of the model (see section III E and Appendix E) as an input to computation of annual cash flow.

3. Capital Expenses

Total capital investment in the ocean mining project of $493 million is divided into costs allocated to three major sectors of the cost model: mining, transportation, and processing. The costs in each of these sectors are further divided according to the sub-sectors that are described in sections B, C, and D of Chapter III and Appendices B, C, and D. The division of the capital investment among the sectors and sub-sectors of the ocean mining project is illustrated in Figure V-2. The costs are presented in greater detail in Table V-2.

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Figure V-2

Allocation of Capital Costs: $493 million

(in millions of dollars)

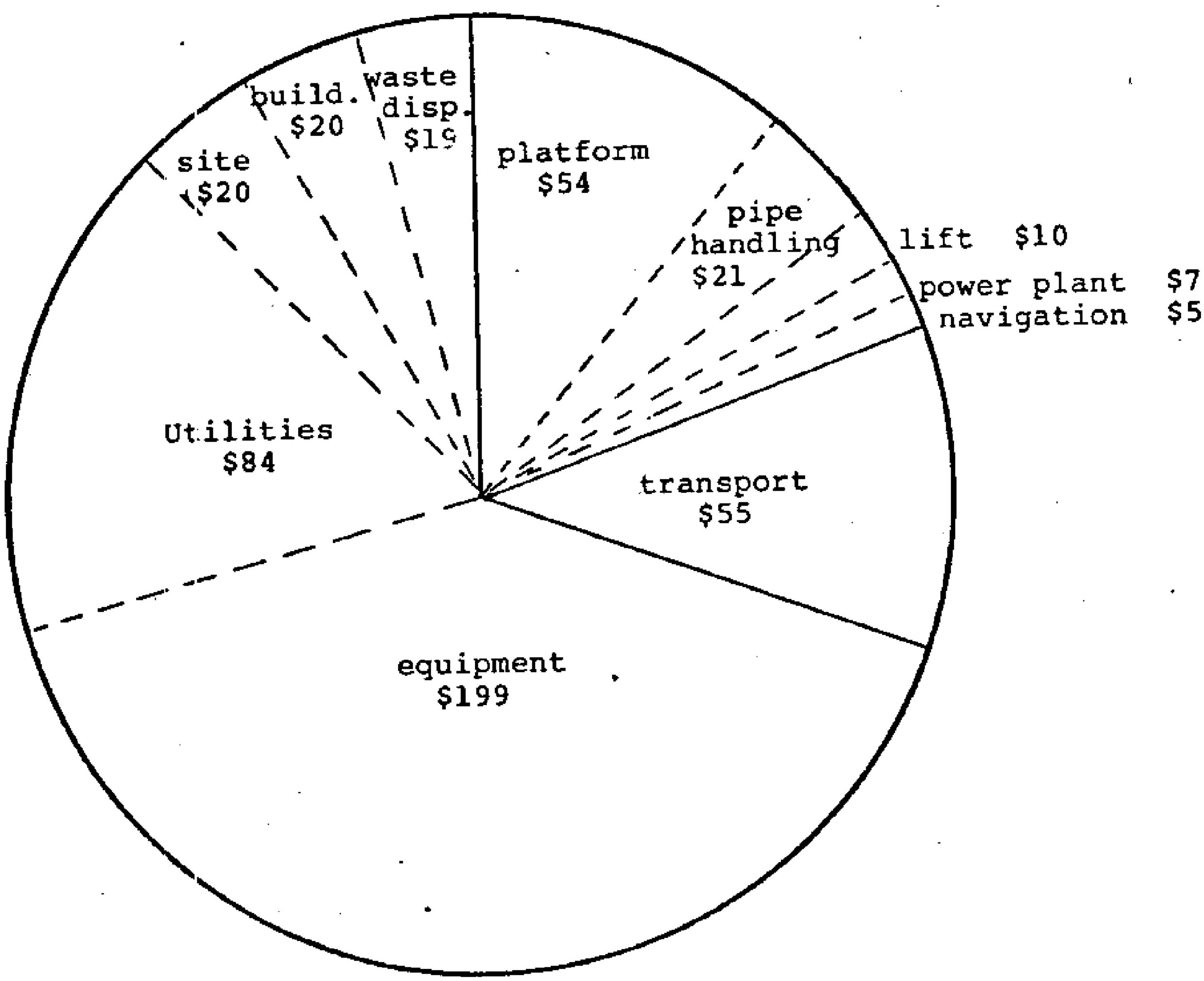

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Table V-2

Pre-Investment and Investment Expenses in the Baseline Model

	Col. 1	Col. 2	Col. 3	Col. 4
1. Research & Development Program				
Total R&D Program Cost				50.00
2. Prospecting and Exploration Program				
Prospecting		1.6		
Exploration				
Research Team Salaries and Benefits	.66			
Discrete Survey	2.60			
Continuous Survey	11.50			
Sub-Total Exploration		14.8		
Total Prospecting and Exploration Program Cost				16.40
3. Capital Investment				
Mining Sector				
Capital Cost per Ship				
Platform	53.77			
Lift System	9.53			
Power Plant	6.82			
Navigation System	5.00			
Pipe Handling System	20.66			
Other Capital	0.00			
Sub Total (per ship)		95.79		
Number of Mineships		1		
Capital Cost of Mining Sector			95.79	
Transport Sector				
Transport Ships	53.3			
Slurry Systems	1.8			
Capital Cost of Transport Sector			55.1	

	Col. 1	Col. 2	Col. 3	Col. 4
Processing Sector				
Processing Equipment				
Materials Preparation	1.20			
Drying & Reduction	29.80			
Wash & Leach	20.04			
Liquid Ion Exchange	33.08			
Electrowinning	11.80			
Stripping Tower	22.56			
Sub Total Processing Equipment		(118.65)		
Processing Equipment (with indirects & fees)		199.34		
Utilities				
Synthetic Gas Plant	22.83			
Power Plant	13.75			
Power Distribution	7.30			
Steam Plant	4.08			
Steam Distribution	1.07			
Cooling Tower	.71			
Sub Total Utilities		(49.75)		
Utilities (with indirects & fees)		83.57		
Buildings				
Sub Total Buildings		(11.87)		
Buildings (with indirects & fees)		19.93		
Site Development				
Wharf	1.25			
Shore Facilities	.66			
Land	.20			
Sub Total Port Facility		(2.11)		
Transportation	2.48			
Development	1.05			
Land Purchase and Preparation	6.39			

	Col. 1	Col. 2	Col. 3	Col. 4
Sub Total Plant Cost		(9.92)		
Total Site Development		(12.03)		
Site Development (with indirects & fees)		20.22		
Waste Disposal				
Land Purchase and Preparation	5.15			
Slurry Transport System	6.25			
Sub Total Waste Disposal		(11.40)		
Waste Disposal (with indirects & fees)		19.95		
Capital Cost of Processing Sector			342.21	
Total Capital Investment Cost				493.05
Total Estimated Capital and Operating Expenses Prior to Commencing Commercial Recovery				559.45

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4. Operating Expenses

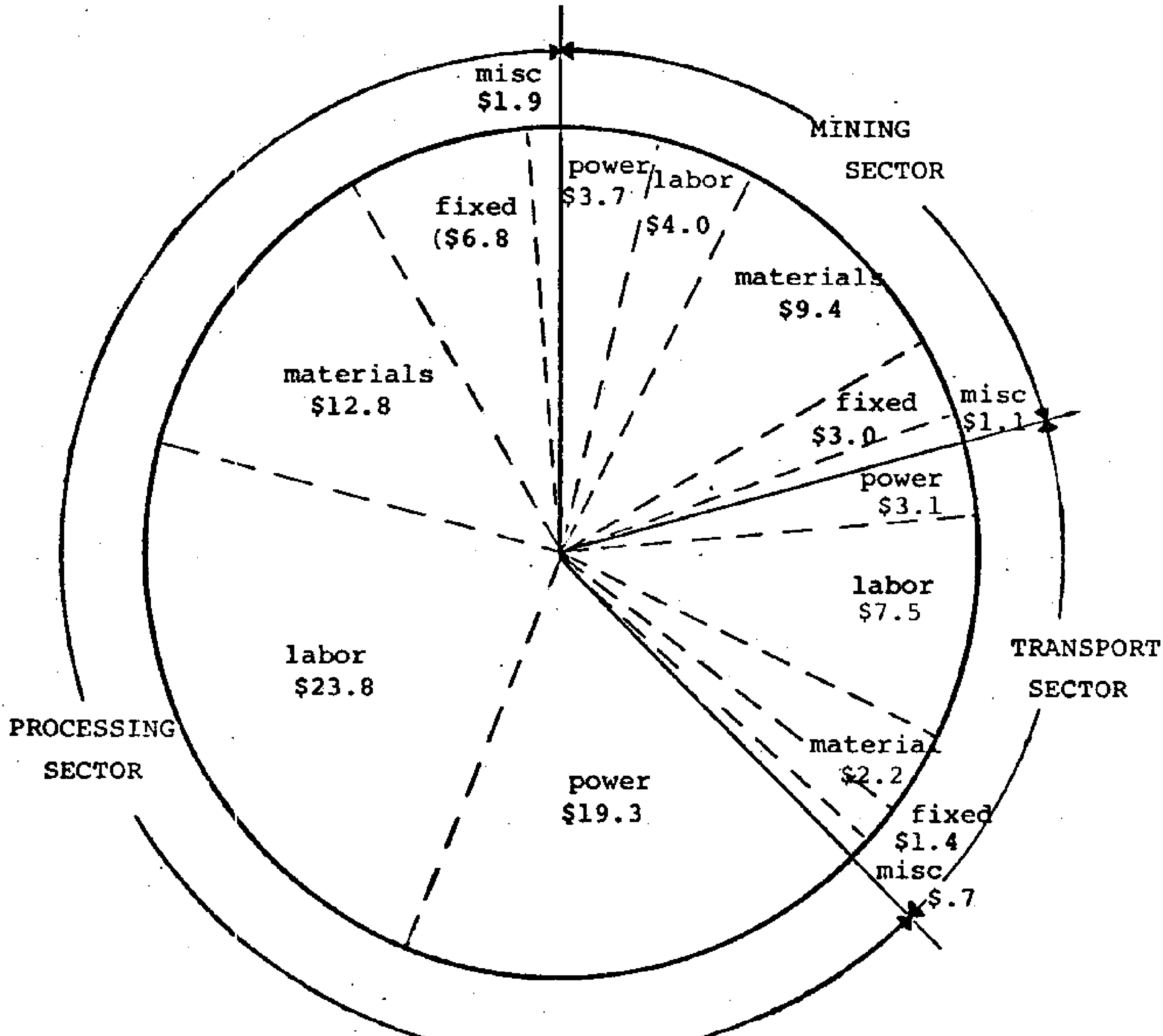
Estimated annual operating costs for the ocean mining project of $100.5 million are also allocated among the mining, transportation and processing sectors. The costs of each sector are further divided into the annual expenses for energy, labor, materials, fixed charges, and miscellaneous items. These costs are shown in Table V-3. The composition of each of these five kinds of expenses is detailed in the appropriate sections of Chapter III. The division of the annual operating expense is illustrated in Figure V-3.

Table V-3

Estimated Annual Operating Costs of the Baseline Model
(in millions of dollars)

Mining Sector		
Energy	3.7	
Labor	4.0	
Materials	9.4	
Fixed	3.0	
Miscellaneous	1.1	
Sub Total Mining Sector		21.1
Transport Sector		
Energy	3.1	
Labor	7.5	
Materials	2.2	
Fixed	1.4	
Miscellaneous	0.7	
Sub Total Transport Sector		14.9
Processing Sector		
Energy	19.3	
Labor	23.8	
Materials	12.8	
Fixed	6.8	
Miscellaneous	1.9	
Sub Total Processing Sector		64.5
Total Annual Operating Cost of Ocean Mining Operation		100.5

Figure V-3
Allocation of Annual Operating Costs
$100.5 Million
(millions of dollars)



C. Changes in Costs Due to Variation of Parameters

Throughout the remainder of this chapter and in the next, a number of analyses are made examining changes in the baseline conditions described in Chapters III and IV from which have been produced the results in sections A and B. These alternative conditions, and the resulting impacts on the project, are examined for two reasons.

In several analyses, a single parameter is changed in order to test the sensitivity of the project as a whole to changes in that one parameter. Such analyses call attention to parameters to which the model is particularly sensitive. In this section, fifty-eight separate variations of this sort have been made to test their impact on the capital and operating costs or the costs of prospecting and exploration. Additional sensitivity tests for impact on economic return (in contrast to costs alone) are made in section D of Chapter VI.

In other analyses, changes are made because a realistic choice may be available to the operator. Should one or two mineships be used, for example? Several such instances are examined in section D below for their impact on costs. In Chapter VI, sections E through I examine somewhat similar changes in operating or financial assumptions for their impacts on economic return.

The changed values for the fifty-eight variables are selected on two bases. In some cases, such as the number of bottom units lost each year, an informed judgment suggested a logical or reasonable alternative to use. In other cases, an arbitrary change of a 10% increase or decrease was made.

The impacts of 10% changes of ten variables that affect exploration costs are presented in Table V-4. (See Chapter IV for full identification of the variables).

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Table V-4

Changes in Exploration Costs
Due to Changes in Selected Variables

Variable	Baseline Value	Test Value	Value Change	Exploration Cost ($ million)	Cost Change ($ million)
Baseline	-	-	0	14.8	0
ARO	3,000,000	2,700,000	-10%	13.4	-1.4
ABB	2.0	1.8	-10%	16.4	+1.6
AAFM	0.8	0.72	-10%	16.4	+1.6
SWEPFF	0.5	0.55	+10%	13.6	-1.2
COLEFF	0.65	0.715	+10%	13.6	-1.2
WNSEF	1.0	0.9	-10%	16.4	+1.6
EXPLBR	660,000	726,000	+10%	14.9	+1.0
MAPCST	432	475	+10%	16.0	+1.2
SOILCS	92	101	+10%	15.1	+0.3
SHRENT	5,000	5,500	+10%	16.1	+1.3

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The results of the variable changes on capital and operating costs are shown in Table V-5 with the new values of costs and the change from baseline results. Three observations may be made from an analysis of these changes.

The first concerns the fact that most input variables in the cost estimation section are used to calculate capital and operating costs of discrete units of equipment in the 12 sub-sectors of the model (see Chapter III). In general, a change in the value of a single variable results in changes in the capital and operating costs of one single unit, with minor changes in associated maintenance and fixed costs. These changes in costs are usually small in comparison to the total capital and operating costs of the project.

Second, there are several variables that are used throughout the model or in the processing sector and so affect costs in a number of sub-sectors. Changes in these have a major impact on total project costs. One of these is the annual rate of ore recovery. It is a particularly critical variable since it affects the estimation of costs in all sub-sectors. A 10% reduction in the recovery rate of nodules results in a 5% decrease in capital and operating costs. The reduced recovery rate also leads to a decrease in gross revenues.

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Table V-5

Changes in Capital and Operating Costs
Due to Changes in Selected Variables

Variable	Baseline Value	Test Value	Change	Capital Cost	Change ($ million)	Operating Cost	Change ($ million)
CDS	.5	.55	+10%	493.0	0	100.4	-0.1
COLWTH	30	33	+10%	492.5	-0.5	100.1	-0.4
DW	18000	16200	-10%	491.5	-1.5	99.3	-1.2
DN	.25	.125	+100%	493.8	0.8	100.8	0.3
FF	.013	.0143	+10%	493.1	0.1	100.5	0
PEF	.65	.585	-10%	493.6	0.6	100.8	0.3
PILF	1.0	0.5	-50%	493.0	0	106.3	5.8
PPRICE	.03	.033	+10%	493.0	0	100.8	0.3
RHON	128	141	+10%	493.8	0.8	100.9	0.4
SEF	.65	.585	-10%	493.2	0.2	100.5	0
STCST	1.0	1.1	+10%	493.1	0.1	100.5	0
WYS	300	270	-10%	500.5	7.5	101.3	0.8
BASMSH	4550000	5000000	+10%	498.4	5.4	101.1	0.6
BUMFAC	.05	0.1	+100%	493.0	0	100.6	0.1
FACINS	3.4	3.74	+10%	493.2	0.2	100.5	0
SHMFAC	.05	0.1	+100%	493.0	0	103.3	2.8
PMMFAC	.05	0.1	+100%	493.0	0	100.5	0
ASCSTL	2100000	2310000	+10%	493.0	0	100.7	0.2
CPLPR	7700	8470	+10%	493.5	0.5	100.9	0.4

Variable	Baseline Value	Test Value	Change	Capital Cost	Change ($ million)	Operating Cost	Change ($ million)
SBUCST	1500000	1640000	+10%	493.3	0.3	101.1	0.6
BUPY	2	3	+50%	494.5	1.5	102.0	1.5
PIPTH	.04	.06	+50%	493.5	0.5	100.9	0.4
ARO	3000000	2700000	-10%	469.1	-23.9	95.0	-5.5
ABB	2.0	1.8	-10%	493.9	0.9	100.9	0.4
COLEFF	.65	.715	+10%	492.5	-0.5	100.1	-0.4
WNSEF	1.0	0.9	-10%	498.3	5.3	101.6	1.1
UPKE	.04	.044	+10%	493.0	0	101.8	1.3
PAYOHD	.25	.20	-20%	493.0	0	100.0	-0.5
PINSRT	.01	.02	+100%	493.0	0	103.9	3.7
STXRT	.01	.02	+100%	493.0	0	103.9	3.7
SCPM	250000	275000	+10%	494.3	1.3	100.5	0
SLRYOP	.01	.02	+100%	493.0	0	101.4	0.9
PMPDTH	3000	1000	-67%	497.2	4.2	103.1	2.6
COALPR	15.0	16.5	+10%	493.0	0	101.6	1.1
STMEFF	0.9	.81	-10%	493.0	0	100.3	-0.2
PPEFF	.33	.363	+10%	493.0	0	100.0	-0.45
SGEXP	.8	.6	-25%	507.9	14.9	101.2	0.87
ARST	200	220	+10%	493.5	0.5	100.2	-0.83
WY	300	270	-10%	515.3	22.3	101.7	1.2
PC	1.0	1.1	+10%	493.0	0	100.1	-0.4
WAGE	8.0	8.8	+10%	493.0	0	101.6	1.1
BFAC	.10	.11	+10%	494.4	1.4	100.3	-0.2
PP	.03	.033	+10%	493.0	0	100.6	0.1
FID	1.4	1.44	+3.6%	502.2	9.2	100.8	0.3
ENGFEE	.05	.055	+10%	493.8	0.8	100.2	-0.3
CONFEE	.15	.2	+33%	506.7	13.7	101.2	0.7
POWLIM	25100	0	-100%	469.3	-23.7	102.5	
POWLIM	25100	60000	+139%	505.8	12.8	77.4	-3.1
F(2),F(4)	1.5,2.5	1.65,2.75	+10%	496.5	6.5	101.6	1.1
P(10)	2400	2880	+20%	493.9	0.9	101.4	0.9
S(11)	1.0	1.1	+10%	493.1	0.1	100.3	-0.2

Three other variables to which the model demonstrates more than average sensitivity are indirect construction costs, contingency fees and engineering fees. These variables together comprise a factor applied to the direct costs figure in each of the five sub-sectors of the processing sector (see Table V-2 and Appendix D, section IIA). Thus each variable affects all components of processing costs, and the processing sector is the largest component of the total project cost. A 10% change (from 40% to 44%) for indirect construction costs results in an increase of 2% on total capital cost. A change in the contingency fee from 15% to 20% gives an increase of 3% in project capital cost.

Finally, the group of variables associated with the lift system of the mining sector appear particularly sensitive. Changes in water depth at the minesite, in the pump submergence depth, and in the efficiency of separation of nodules from the lift discharge each results in changes of capital and operating costs of more than one million dollars. In addition, the change from an expected lifetime for the lift pipe from one year to six months results in an increase of $5.8 million in annual operating cost.

The impacts on project profitability of changes in recovery rate, lift system cost and other capital and operating costs discussed above are examined in Chapter VI.

D. Variations of Assumptions of the Model

As indicated earlier, a second type of change in model paramaters concerns different basic design or systems assumptions. In many cases, different proposed ocean mining systems are based on differing operating or design assumptions. In this section, the impacts on costs of three such areas are examined. The areas are the use of two rather than one mineship, assumption of different (longer) distances from port facility to processing plant and from processing plant to waste disposal site, and use of U.S. as opposed to foreign-built transport ships and U.S. operating crews. These analyses provide some comparison among different conceptual or operational approaches while simultaneously indicating the rough sensitivity of the model to changes in the pertinent parameters.

1. Multiple Mineship System

The mining system used in the baseline model assumes that mining operations are conducted from a single mineship. While this method has been proposed by at least two companies considering investments in ocean mining[1], at least one company is considering the use of two mineships[2], with each ship designed to recover nodules at half the rate required of a single ship. A major advantage of the two ship system is that it reduces the forward velocity of the mineship by half. The change is from 3.6 knots (5.9 feet per second) for the single ship as in the baseline model, to 1.8 knots (3 feet per second) for each of the two mineships. Because drag forces on the pipe decrease at a rate greater than the decrease of velocity, the stresses on the lift pipe are greatly reduced for the two ship system. The lower stresses may result in longer lifetime of the components of the lift system or they may allow the system to be constructed of lower cost in components.

The model has been tested for two variations of the baseline conditions. The first is the use of two mineships with all costs calculated from the same parameters used in the single mineship case. The second test uses two mineships, but in this case several other parameters have been changed to reflect the lower pipe stresses. The lifetime of the lift pipe is increased from one to two years, the number of bottom units lost per ship per year is reduced from two to one, and the cost of couplings for the pipe string is reduced by 25% from $7700 each to $5775.

The results for the baseline run and the two tests for the two mineship systems, presented in Table V-6, indicate significant increase in costs, an 11% increase in capital cost and a 17% increase in operating cost in the first variation. In the second variation the capital cost is increased by 10%, but the operating cost is increased only 7%. The total costs of both two ship systems are increased due to the increased cost of the transportation sector as well as the costs of the mining sector.

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Table V-6

Comparison of Various Mining Systems

Mining Sector	One Mineship	Two Mineships	Two Modified Mineships
Platform	53.8	82.1	82.1
Pipe Handling System	20.7	27.3	27.3
Power Plant	6.8	6.2	6.2
Lift System	9.5	18.3	12.9
Navigation and Control	5.0	10.0	10.0
Sub Total	95.3	143.8	138.5
Transportation Sector			
Ships and Transfer Pumps	55.1	62.2	62.2
Processing Sector			
Process Equipment	199.3	199.3	199.3
Utilities	83.6	83.6	83.6
Site Development	20.2	20.2	20.2
Buildings	19.9	19.9	19.9
Waste Disposal	19.2	19.2	19.2
Sub Total	342.2	342.2	342.2
Total Capital Costs	493.0	548.2	542.9
Mining Sector			
Energy	3.7	3.4	3.4
Labor	4.0	7.2	7.1
Materials	9.4	18.0	8.5

	One Mineship	Two Mineships	Two Modified Mineships
Fixed	3.0	4.5	4.5
Miscellaneous	1.1	1.7	1.3
Sub Total	21.1	34.8	24.8
Transportation Sector			
Energy	3.1	3.5	3.5
Labor	7.5	9.8	9.8
Materials	2.2	2.8	2.8
Fixed	1.4	1.3	1.3
Miscellaneous	0.7	0.9	0.9
Sub Total	14.9	18.3	18.3
Processing Sector			
Energy	19.3	19.3	19.3
Labor	23.8	23.8	23.8
Materials	12.8	12.8	12.8
Fixed	6.8	6.8	6.8
Miscellaneous	1.9	1.9	1.9
Sub Total	64.5	64.5	64.5
Total Operating Costs	100.5	117.6	107.6

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2. Increased Transportation Distances

Increases in distances for which transportation must be provided are likely to vary from project design to project design. The impact on both capital and operating costs can be significant. In this analysis, distance from the port facility to the processing plant was increased from five miles to 25 miles and the distance between the processing plant and the waste disposal area was increased from 25 miles to 125 miles.

Expectedly, the increased distances result in both increased capital and operating costs. The capital costs of the port to plant slurry pipeline are included in the site development sub-sector and the cost of the plant to disposal area pipeline is included in the cost of the waste disposal sub-sector. Significantly, the additional costs of the longer pipelines result in an 11% increase in total capital cost.

The operating costs of both pipelines are included in the miscellaneous operating costs of the processing sector. The results of the test of the increased transportation distances are compared to the baseline costs of the processing sector and are presented in Table V-7.

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Table V-7

Effects of Increased Land Transportation Distances
(in millions of dollars)

Processing Sector Capital Costs	Baseline	Increased Distances
Processing Equipment	199.3	199.3
Utilities	83.9	83.6
Site Development	20.2	29.0
Buildings	19.9	19.9
Waste Disposal	19.2	62.2
Total Processing Sector	342.2	394.0
Processing Sector Operating Costs		
Energy	19.3	19.3
Labor	23.8	25.2
Material	12.8	14.1
Fixed	6.8	7.9
Miscellaneous	1.9	5.5
Total Processing Operating Costs	64.5	71.9

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3. U.S. Construction and Crew Costs for the Transportation Sector

Two operational choices confronting prospective ocean mining operators are whether transport ships are to be built in U.S. or foreign construction facilities and whether to use U.S. or foreign crews. Related choices underlie a continuing policy issue in the U.S. maritime industry. The baseline model assumes foreign construction and foreign crews. Analysis of the impact of using U.S. construction facilities and U.S. operating crews indicates a difference of approximately 7% in construction costs and as much as 6% in operating costs. The latter range is provided by using labor costs derived both as detailed in Appendix C and from using data of an independent consultant under contract to the National Oceanographic and Atmospheric Administration to provide transport sector cost estimates.[3] These results are presented in Table V-8.

The analysis suggests that use of U.S. construction facilities and operating crews will raise capital and operating costs. This conclusion holds for data generated in both this study and that of the independent contractor. The legal, policy and profitability aspects are considered in Chapter VII along with other options facing U.S. legislators.

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Table V-8

Transportation Cost Changes Caused by Use of U.S. Construction Facilities and Crews (in millions of dollars)

	Baseline (Foreign Construction & Crew)	U.S. Construction & Crew	Independent Source, Foreign Construction & Crew	Independent Source, U.S. Construction & Crew
Capital Costs				
Ships	53.3	87.4	53.3	87.4
Slurry Systems	1.8	1.8	1.8	1.8
Total	55.1	89.2	55.1	89.2
Operating Costs				
Energy	3.1	3.1	3.1	3.1
Labor	7.5	13.2	3.3	8.4
Materials	2.2	2.8	2.2	2.8
Fixed Capital Charges	1.4	1.4	1.4	1.4
Miscellaneous Charges	.7	.7	.7	.7
Total	14.9	21.2	10.7	16.4

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Chapter V Notes

1. Arthur D. Little, Draft Report, p. 14 and p. 75.
2. Ibid., p. 33.
3. Andrews, Benjamin V., Relative Costs of U.S. and Foreign Nodule Transport Ships, Report prepared for Department of Commerce, Report No. 7-13775, August 1977, Table IV-3.

CHAPTER VI. RESULTS OF ECONOMIC RETURN ANALYSIS

A. Introduction

In this chapter, the projected operational results are summarized and the analyses of the economic return to the investor from the hypothetical project's operations are presented in Section B. After a brief note on the presentation of economic return measures used hereafter in the study (Section C), a variety of analyses are made to examine the impact on economic return of changes in values or assumptions. Section D makes increases or decreases of 25% of several important variables in a manner similar to those made concerning costs in Section C of Chapter V. Sections E-I analyze several changes in financial assumptions which affect the economic return of the project. These sections are analogous to Section D of Chapter V.

B. Summary of Baseline Operational Results and Economic Return Analysis

The project based on the conditions and assumptions summarized in Chapter III goes into commercial production in its sixth year. Its annual production and revenues from then through the thirtieth year are as follows.

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Table VI-1: Annual Production and Revenue

	Annual Production (lbs. x 10^6)	Revenue ($ x 10^6)
Nickel	85.5	171.0
Copper	74.1	52.61
Cobalt	8.64	34.56
Manganese	0.	0.
TOTAL ANNUAL REVENUE		258.17

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Under the baseline assumptions of Chapter III and initial values of Chapter IV, the project does not report a loss for any year of commercial production. Annual cash flow turns positive in the first year of production and remains so for the life of the project.

Three measures of economic return are routinely provided in this report in analyzing the impact of technological choices and regulatory policies on operations: net present value (NPV), internal rate of return (IROR), and payback period. They are calculated from the annual cash flows, as explained in Chapter III, Section E 4.

The net present values (NPV) for different discount rates applied to the baseline case, i.e., the results using the assumptions, conditions and parameter values in Chapters III and IV, are shown in Table VI-2.

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Table VI-2: Net Present Values for Baseline Case at Different Discount Rates

Discount Rate	8%	10%	12%	14%	16%	18%	20%	22%	24%
NPV	349.07	229.99	144.60	82.39	36.43	2.06	-23.89	-43.63	-58.73

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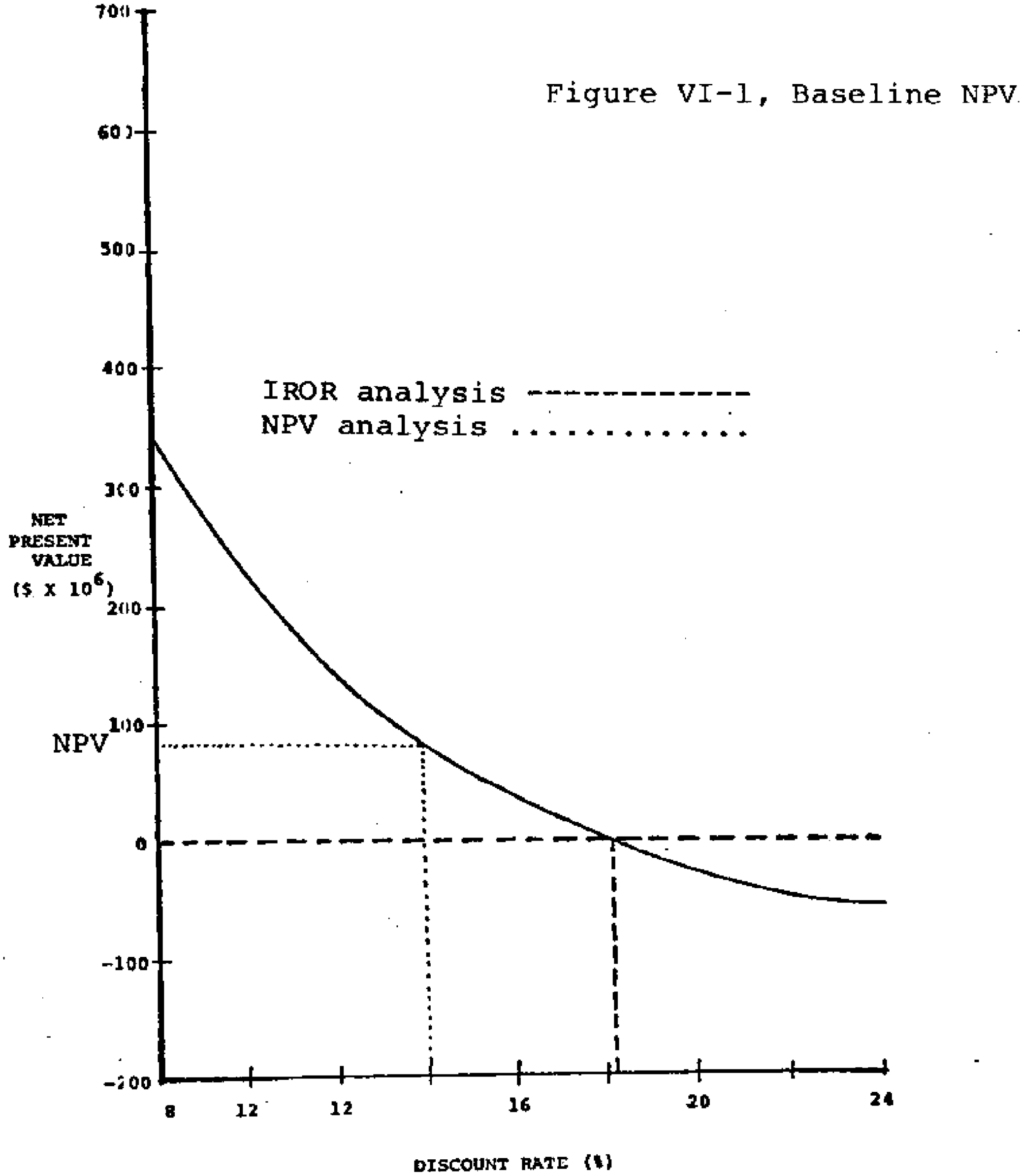
The internal rate of return (IROR) for the baseline project is 18.14%. The payback period is 5.4 years.

C. Display of Economic Return Measures

Determination of NPV is dependent upon selection by the program user of an appropriate discount rate as indicated in Chapter III, Section E 3 a. In order to present the maximum information about the profitability of the project, the results for project net present value are computed for a range of values of discount rate, ranging from 8% to 24%. The results for the baseline case, presented above in tabular form (Table VI-2), are presented in graph form in Figure VI-1. The reader is thus able



NOTE: In order to find the <u>Net Present Value</u> of the project for a specific discount rate, one finds the point on the project curve that corresponds to the desired discount rate. In Figure VI-1, for a discount rate of 14%, first locate the value of 14% on the horizontal axis. Next, follow the dotted line upward to the solid curve that represents the baseline project. Follow the dotted line to the left axis. The intersection of the line with the axis gives the NPV, $82.39 million, for the project using a discount rate of 14%.

The <u>Internal Rate of Return</u> of a project is the value of discount rate that results in an NPV equal to zero. The graphical display in Figure VI-1 can also be used to determine the IROR. First find the point on the vertical axis where the NPV is zero. From this point move right along the dashed line to the point where the line intersects the project curve. From the point of intersection, follow the dashed line down to the horizontal axis and read the corresponding value of discount rate (18.14%), which is the IROR for the project.

to choose the desired discount rate. If, for example, the user chooses to discount his evaluation of future returns at 16%, the project investment would provide sufficient cash flows to satisfy this requirement and yield an additional sum, the present value of which is $36.43 million. In contrast to NPV, IROR and payback period are discrete values for any given set of conditions.

In the analyses that follow, NPV is presented in graph form with NPV for the baseline condition represented by a solid curve. NPV for the particular alternative conditions being analyzed are represented by dashed curves. NPV data for the analyses are presented in tabular form in Appendix G. The model's computer program has the capability to print out tabular NPV data at the end of the operating statements generated for any set of conditions.

IROR and payback data are presented at the bottom of each NPV graph.

Although NPV has several advantages as a measure of economic return (see Chapter III E), IROR and payback will be the measures used to compare alternatives, as these are widely used in the extractive industries. Designation of a particular discount rate for evaluating ocean mining, not an objective of this study, remains the choice of the user.

D. Changes in Economic Return Due to Variation of Parameters

As in Section C of Chapter V, several critical parameters were varied to test their sensitivity of the model's calculation of economic return to these values. In this section, values are most frequently changed by an arbitrary amount -- 25%. The changes analyzed in Section E 1 result from making different assumptions about several critical operational or financial parameters.

1. Gross Annual Revenue and Determinants

a) Revenue. Revenue is the most significant of the four accounting categories -- revenues, total costs, capital allocation and tax elements -- which ultimately determine the size of the annual cash flow.

To test the sensitivity of the model to variations in revenue, this parameter was first increased and then decreased 25% from the baseline condition. The impacts were substantial, as might be predicted. The 25% increase in revenue generated an increase in IROR to 24.45%, indicating the favorable marginal profitability of the operation. Similarly, the comparable decrease in revenue caused a decrease in projected IROR to 9.51%. The figures are shown in Figure VI-2.

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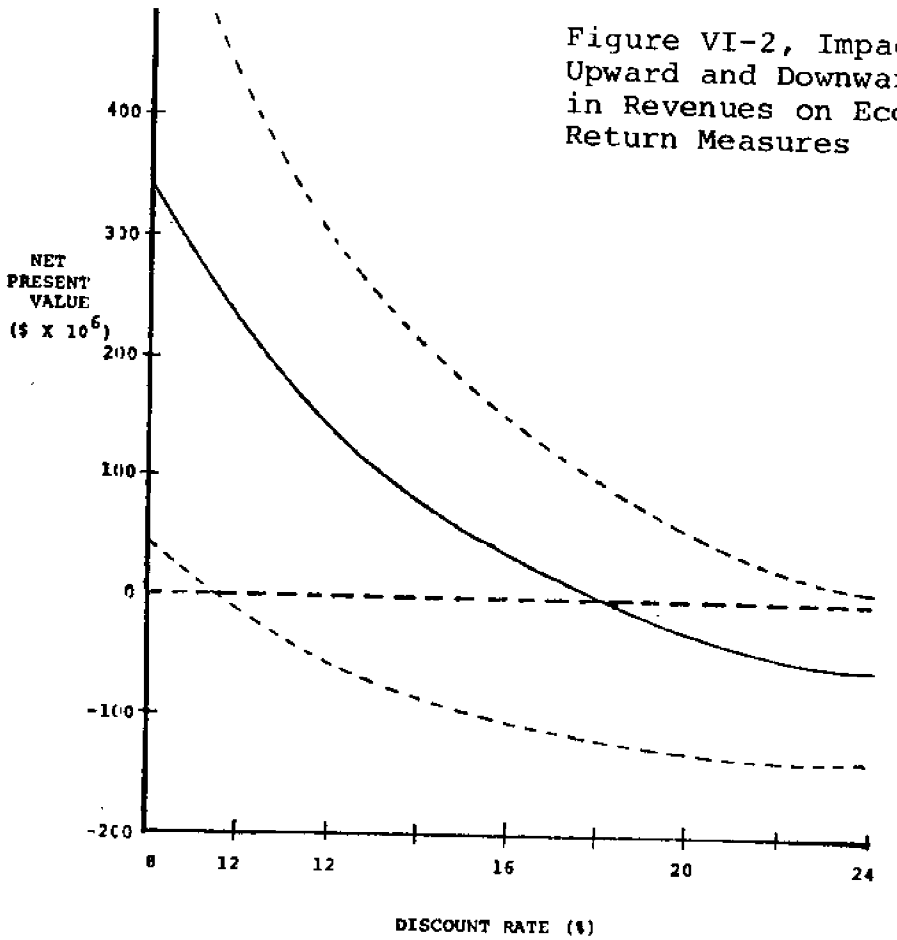

Figure VI-2, Impacts of 25% Upward and Downward Shifts in Revenues on Economic Return Measures

	Upward Shift	Baseline	Downward Shift
IROR (%)	24.45	18.14	9.51
Simple Payback (years)	3.6	5.4	12.0

Revenue is responsive to: the prices obtained for the mined minerals, their rate of production, and the inflation rate. Because of the importance of revenue on economic return, the impacts of changes in these components were also examined.

b) Mineral Prices. Revenues from nickel production account for two thirds of total revenue in the baseline model. Increases and decreases in the market price of the mineral expectedly would have a substantial economic impact. An analysis of a 25% change both upward and downward shows this to be so, as indicated in Figure VI-3.

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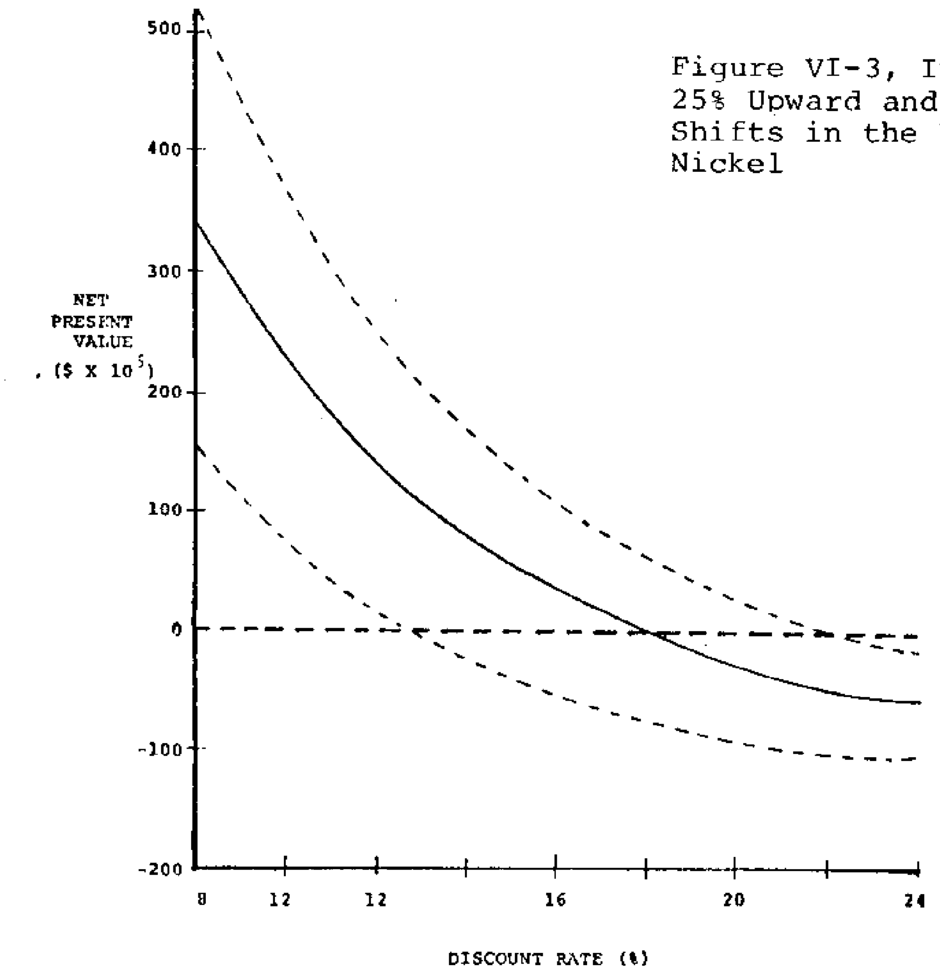

Figure VI-3, Impacts of 25% Upward and Downward Shifts in the Price of Nickel

	25% Increase	Baseline	25% Decrease
IROR (%)	22.44	18.14	12.78
Simple Payback (years)	4.1	5.4	9.2

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A similar 25% increase in cobalt prices causes a much smaller projected change in economic return, because cobalt accounts for only approximately 13% of revenues in the baseline model. The results are shown in Figure VI-4.

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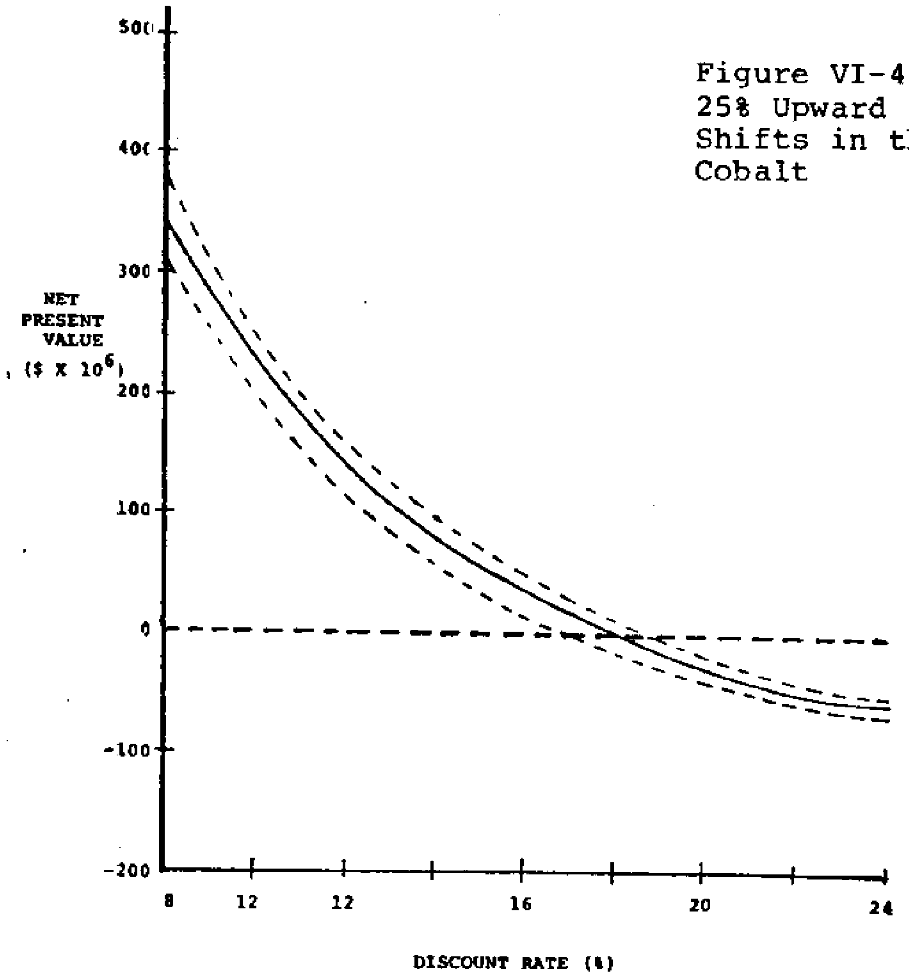

Figure VI-4, Impacts of 25% Upward and Downward Shifts in the Price of Cobalt

	25% Increase	Baseline	25% Decrease
IROR (%)	18.91	18.14	17.12
Simple Payback (years)	5.1	5.4	5.8

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c) Production Rate. The gross revenues of the project are directly proportional to the annual recovery rate of nodules. Thus a mining operation designed to recover 3.5 million tons of nodules per year instead of the 3 million ton per year assumed in the baseline model, will have an increase of approximately 17% in gross revenues. The increase in revenues, however, is accompanied by an increase in capital and operating costs, as noted in Section C of Chapter V. The economic return results for operations designed to process 3.5 and 2.5 million tons per year are presented in Figure VI-5. However, the model can not be expected to test accurately the possibilities of economies of scale much beyond those examined in this exercise. This limit arises because the mining and processing sector design considerations constrain the extent to which the assumptions set out in Chapter III and the technical appendices can be extended.

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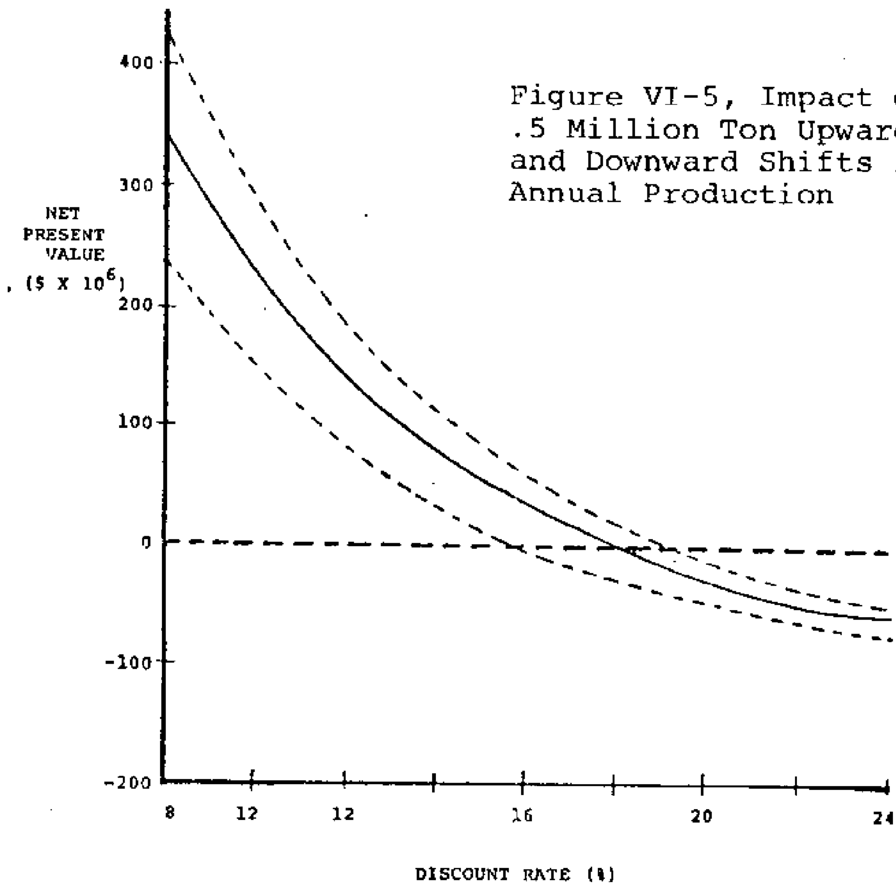

Figure VI-5, Impact of .5 Million Ton Upward and Downward Shifts in Annual Production

	3.5 Million	Baseline	2.5 Million
IROR (%)	19.54	18.14	16.05
Simple Payback (years)	4.9	5.4	6.2

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A different kind of situation which frequently occurs in the start-up of new ventures is for production to be reduced and operating expenses increased during the initial years of commercial recovery. The first and second years of commercial production are set at 70% and 85%, respectively, of the scheduled level. Operating expenses are 30% and 15% higher than projected. As indicated in Figure VI-6, the internal rate of return dropped to 15.82 and the payback period increased 1.1 years to 6.5 years.

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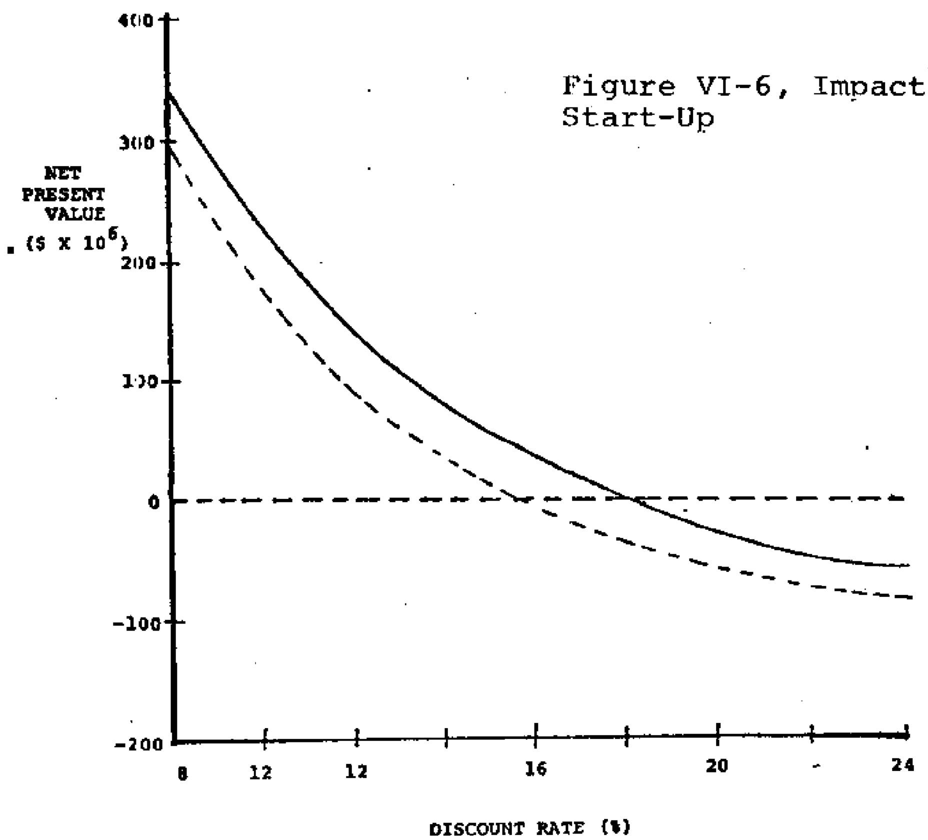

Figure VI-6, Impact of Slow Start-Up

	Baseline	Slow Start-Up
IROR (%)	18.14	15.82
Simple Payback (years)	5.4	6.5

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d) Ore Grade. The grade of the ore will also affect production level, and in another analysis, it was assumed that the combined nickel and copper in the mined nodules averages 2.0% (1.1% Ni, .9% Cu) rather than 2.8% (baseline study), still feeding a 3 million TPY operation. The results suggest a marked worsening of the economic prospects for the venture, with IROR decreasing to 11.16% and payback period increasing to 10.6 years, as is shown in Figure VI-7.

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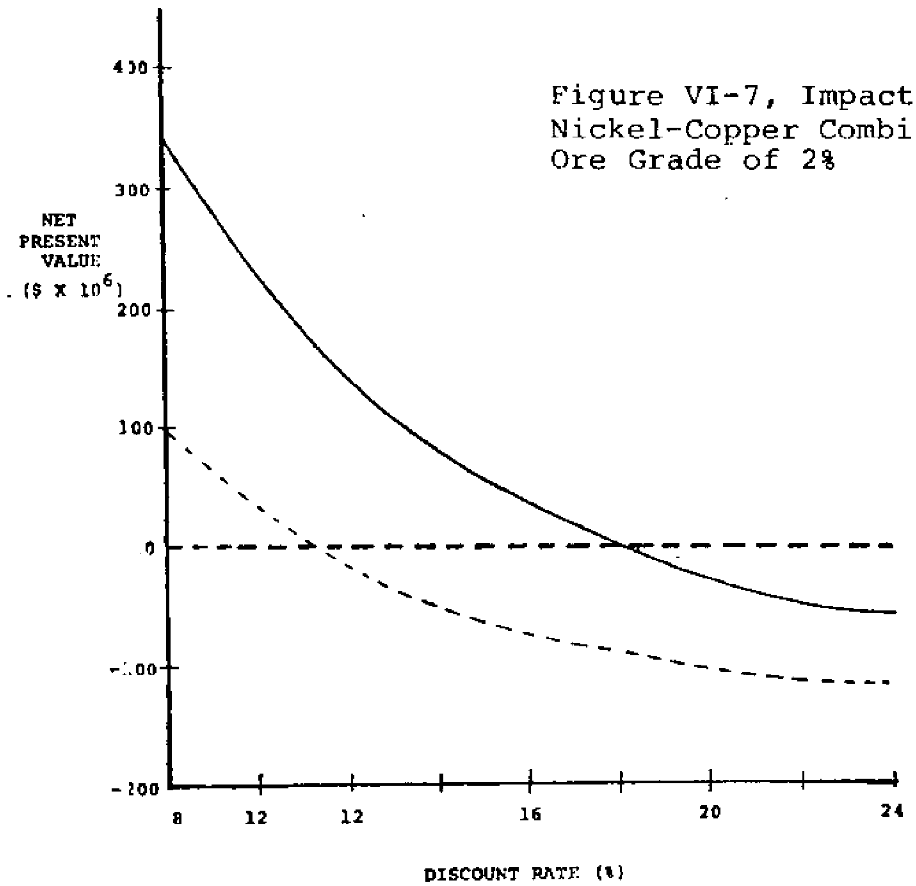

Figure VI-7, Impact of Nickel-Copper Combined Ore Grade of 2%

	Baseline	2% Combined Ore Grade
IROR (%)	18.14	11.16
Simple Payback (years)	5.4	10.6

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2. Annual Operating Costs and Components

The effects of variations in the annual operating cost of the mining project are less pronounced than those resulting from variations of the same percent in gross revenue. The effects on the profitability of the project of a 25% increase and decrease in the total annual operating cost amount to approximately a three percentage IROR swing each way. The results are shown in Figure VI-8.

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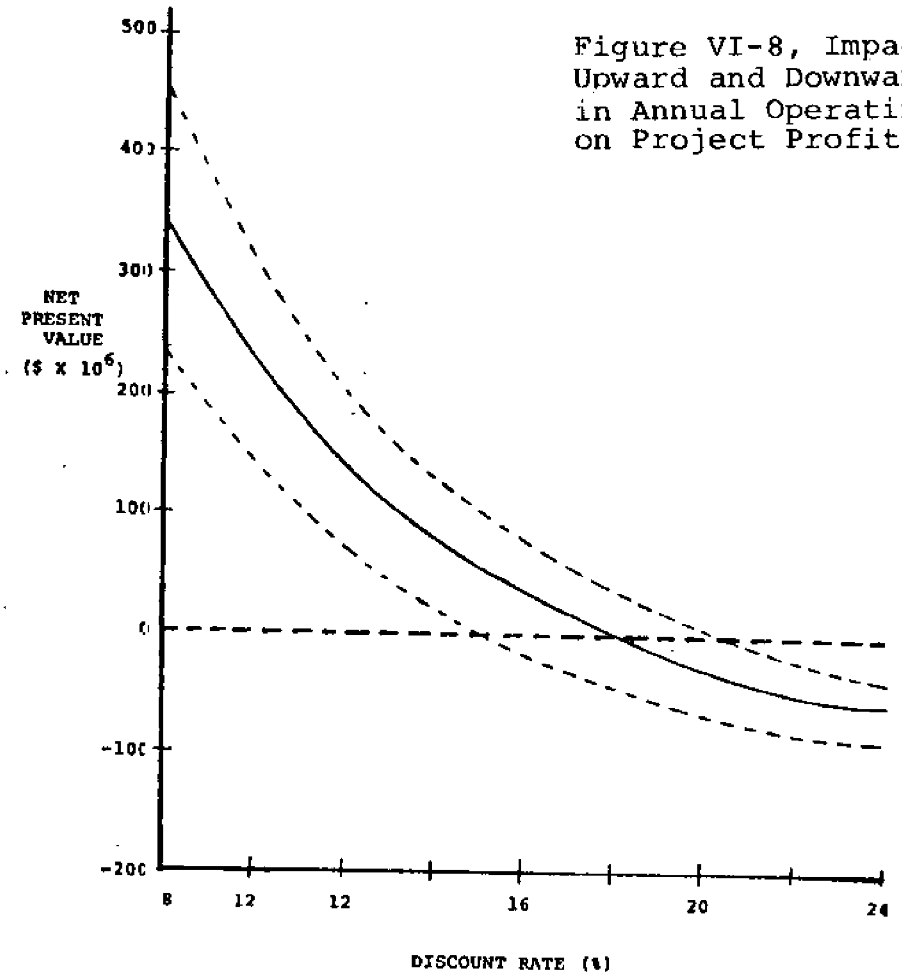

Figure VI-8, Impact of 25% Upward and Downward Shifts in Annual Operating Costs on Project Profitability

	25% Increase	Baseline	25% Decrease
IROR (%)	15.07	18.14	20.72
Simple Payback (years)	7.0	5.4	4.6

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The four operating cost groups of each sector have been grouped by type (energy, labor, materials and fixed) and each type has been varied by 25%. These results are shown in Figures VI-9 through VI-12, respectively.

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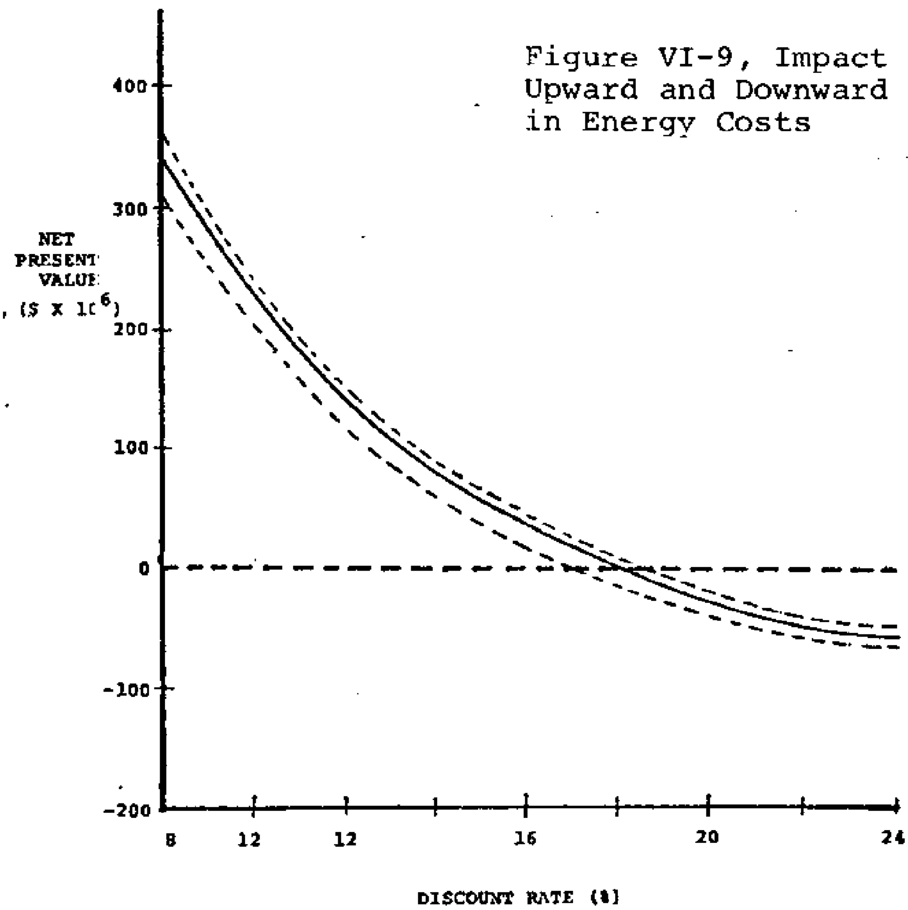
Figure VI-9, Impact of 25% Upward and Downward Shifts in Energy Costs



	25% Increase	Baseline	25% Decrease
IROR (%)	17.29	18.14	18.75
Simple Payback (years)	5.8	5.4	5.2

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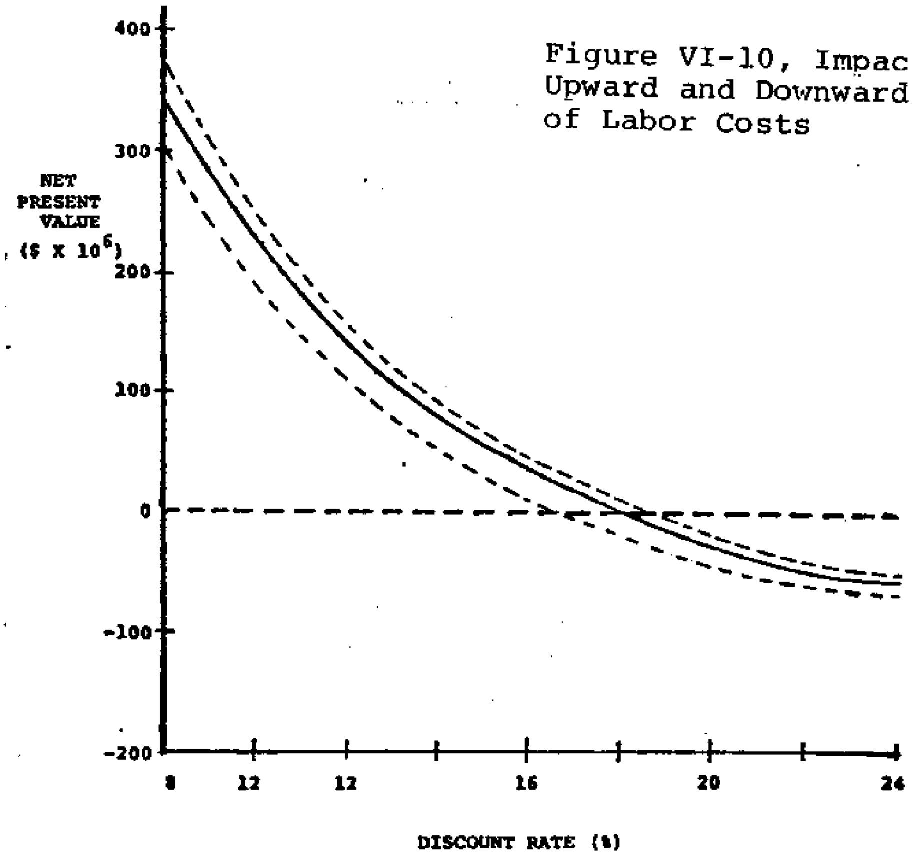
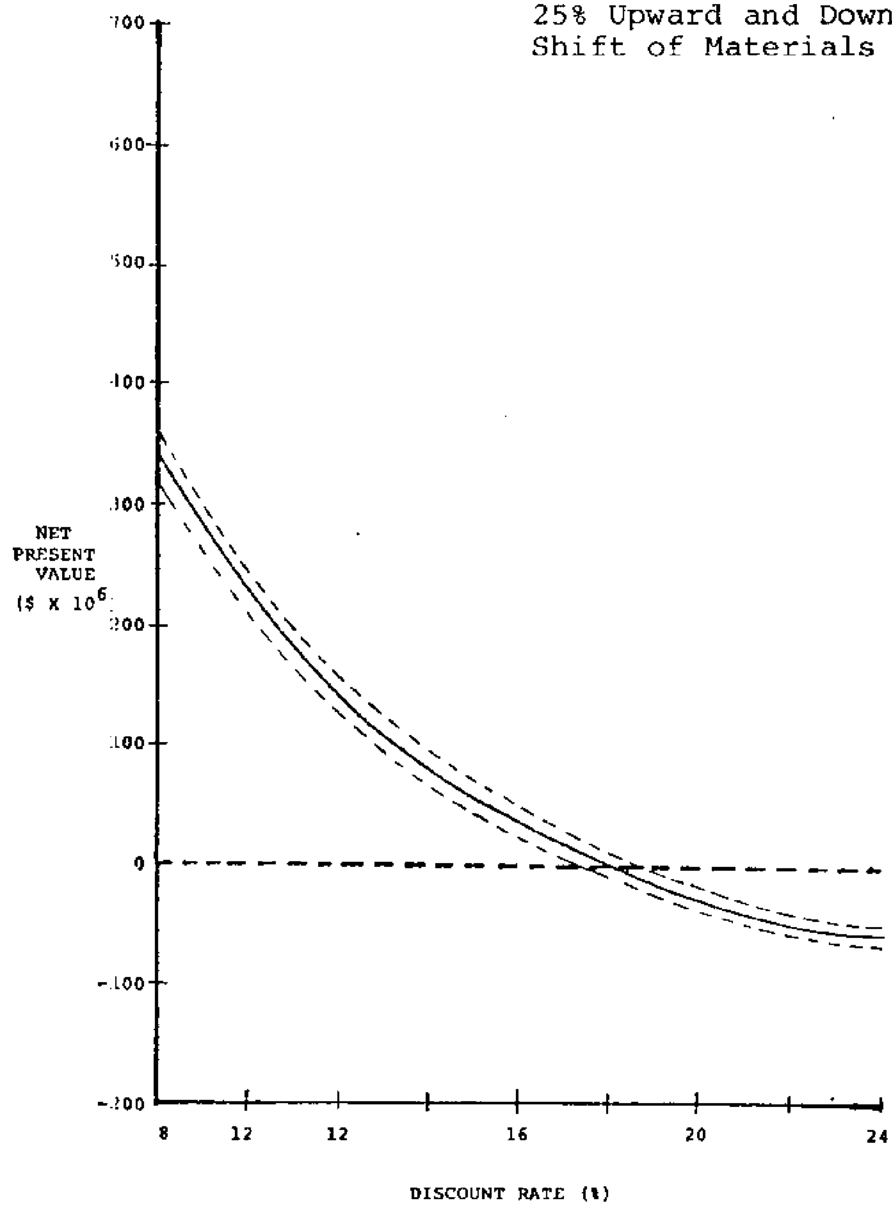


Figure VI-10, Impact of 25% Upward and Downward Shifts of Labor Costs

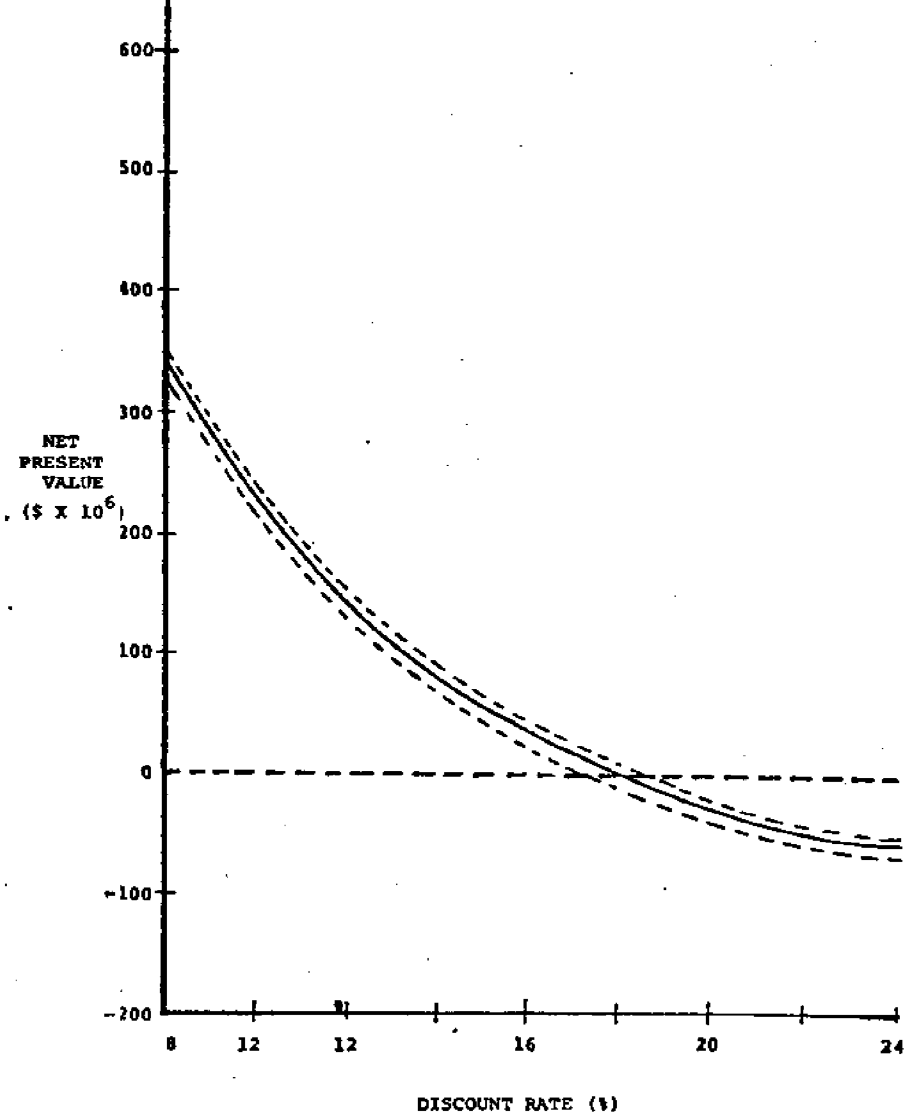
	25% Increase	Baseline	25% Decrease
IROR (%)	17.06	18.14	18.96
Simple Payback (years)	5.9	5.4	5.1

Figure VI-11, Impact of 25% Upward and Downward Shift of Materials Cost



	25% Increase	Baseline	25% Decrease
IROR (%)	17.37	18.14	18.67
Simple Payback (years)	5.7	5.4	5.2

Figure VI-12, Impact of 25% Upward and Downward Shifts of Fixed Costs



	25% Increase	Baseline	25% Decrease
IROR (%)	17.65	18.14	18.40
Simple Payback (years)	5.7	5.4	5.3

3. Total Capital Costs and Components

The effects of 25% changes in the total capital cost of the mining project are similar in magnitude to those that result from 25% changes in annual operating costs. The effects of these changes on the project profitability are roughly the same as a comparable variation in operating costs, except that the impact of a decrease in capital costs is more pronounced. The results are shown in Figure VI-13.

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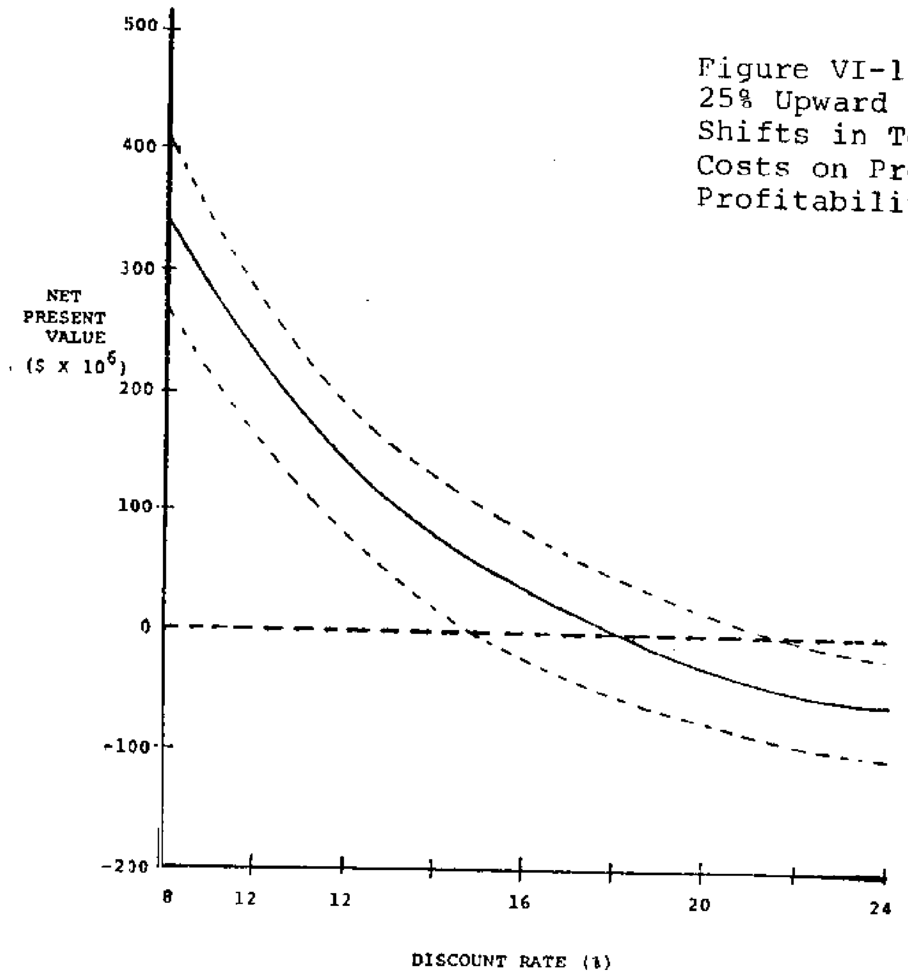

Figure VI-13, Impact of 25% Upward and Downward Shifts in Total Capital Costs on Project Profitability

	25% Increase	Baseline	25% Decrease
IROR (%)	15.01	18.14	21.98
Simple Payback (years)	7.6	5.4	3.7

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The results of the sensitivity analysis performed in Chapter V on the variables of the cost estimation section showed that the total capital and operating costs of the mining project changed on the order of several million dollars when different input variables were changed. More striking changes illustrated in Figure VI-14 through 16 might result from alterations in the basic design of the sub-sectors of the model. For example, unforeseen problems in the construction

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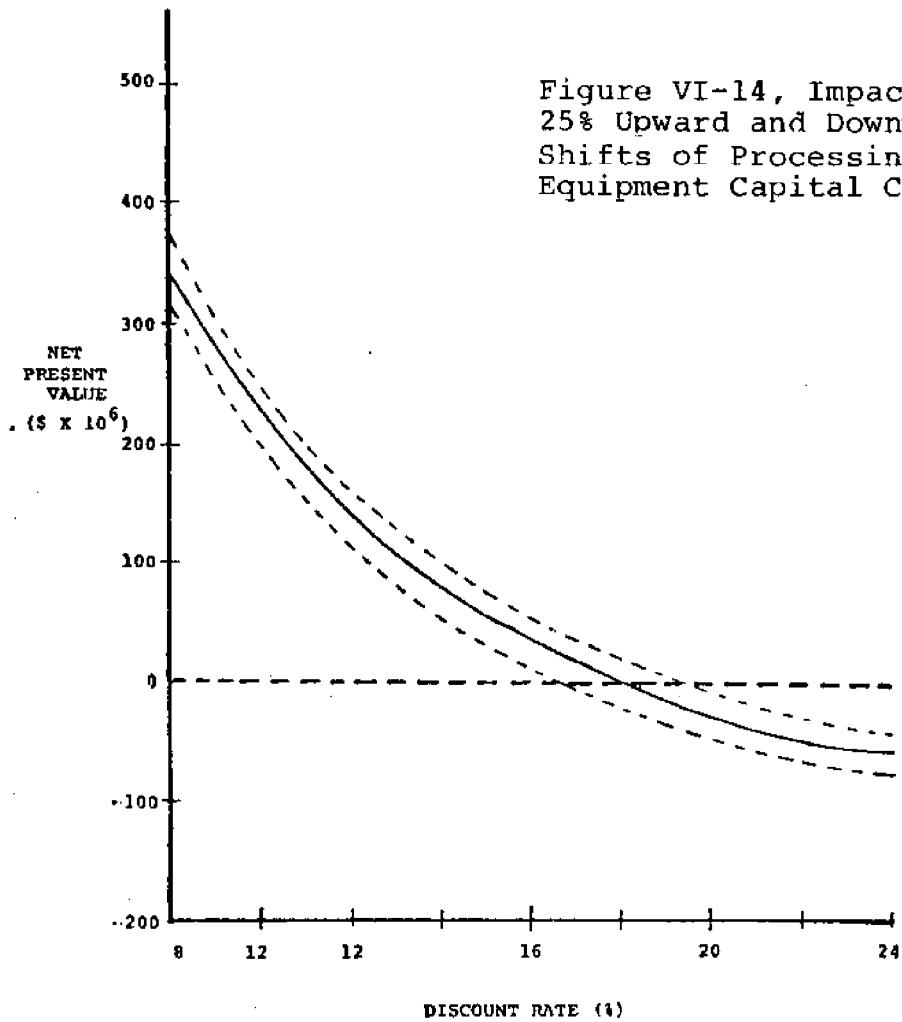

Figure VI-14, Impact of 25% Upward and Downward Shifts of Processing Equipment Capital Costs

	25% Increase	Baseline	25% Decrease
IROR (%)	16.81	18.14	19.62
Simple Payback (years)	6.2	5.4	4.6

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of equipment or from the imposition of environmental regulations on the project might require technological changes.

In order to provide an estimate of the impact of higher and lower costs in the different sub-sectors, analysis was made of those believed most sensitive to change in design or environmental restriction. These groups are: the mining platform, the pipe handling system, and the lift system, all in the mining sector; and, the cost of process equipment, utilities, site development, and waste disposal in the processing sector.

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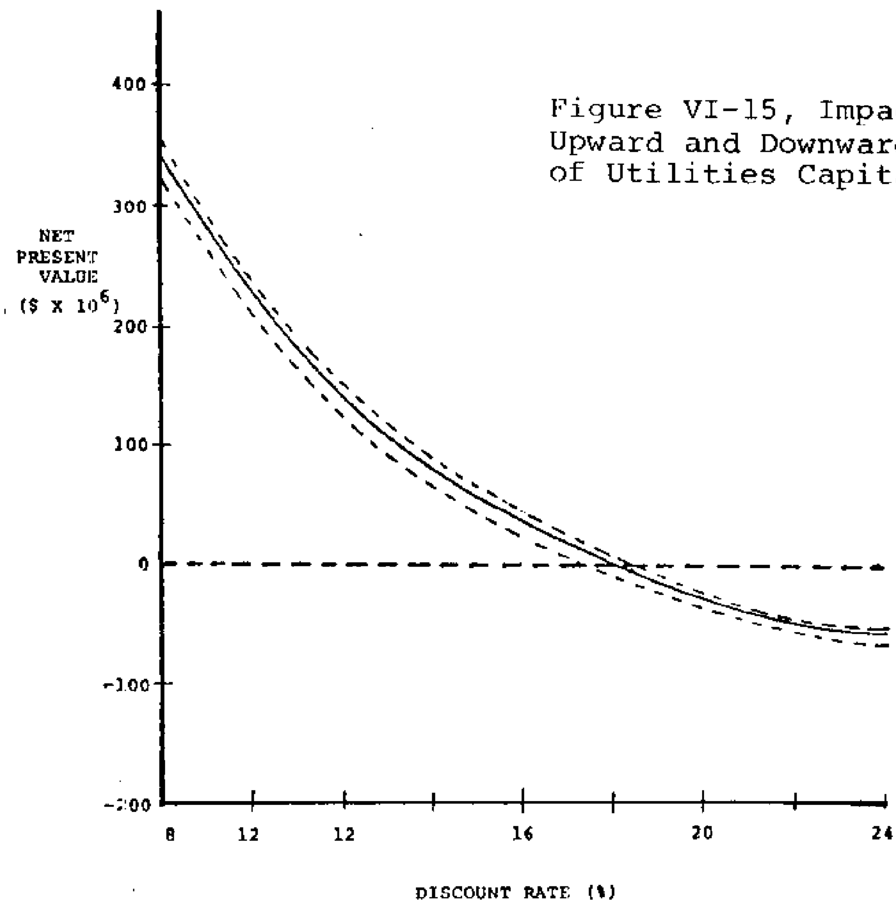

Figure VI-15, Impact of 25% Upward and Downward Shifts of Utilities Capital Costs

	25% Increase	Baseline	25% Decrease
IROR (%)	17.44	18.14	18.64
Simple Payback (years)	5.8	5.4	5.1

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All such costs have been separately increased and decreased by 25%. The results of the 25% change in costs of the process equipment, utilities and transport ship sub-sectors are presented in Figures VI-14, VI-15, and VI-16, respectively. The effects of a 25% change in the costs of the mining platform, the pipe handling system, the lift system, and waste disposal sub-sector are too small to be illustrated by a graph. The

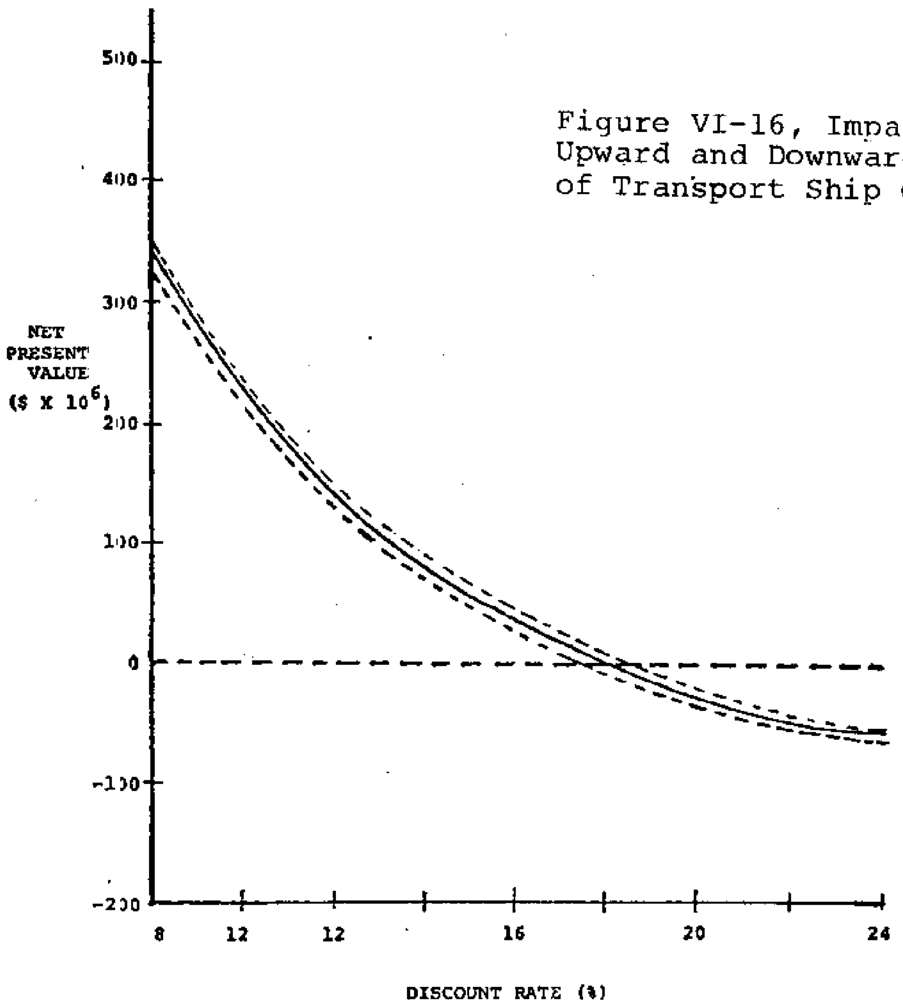

Figure VI-16, Impact of 25% Upward and Downward Shifts of Transport Ship Costs

	25% Increase	Baseline	25% Decrease
IROR (%)	17.58	18.14	18.47
Simple Payback (years)	5.8	5.4	5.2

corresponding internal rates of return and simple payback periods for these evaluations are presented in Table VI-3.[1]

Table VI-3:
Results of 25% Upward and Downward Shifts on Platform, Pipe Handling, Lift System, and Waste Disposal

Variation		IROR(%)	Simple Payback (years)
Baseline Model		18.14	5.4
Platform	+25%	17.65	5.7
Platform	-25%	18.40	5.3
Pipe Handling	+25%	18.04	5.4
Pipe Handling	-25%	18.24	5.3
Lift System	+25%	18.11	5.4
Lift System	-25%	18.17	5.3
Waste	+25%	18.03	5.4
Waste	-25%	18.25	5.3

4. Summary

As instruments for checking the model's validity, the exercises reported above indicate that the model produced expected, predictable changes in the measures of economic return when several of the major variables were varied by large amounts.

These exercises also suggest that in a real life ocean mining operation, meeting projected revenue and production schedules will be important to meeting the investors' expectations, a critical but unstartling observation.

Perhaps more significant, fluctuations in world minerals prices would also have appreciable effects of the attractiveness of the operation, although the analysis indicates that even with a 25% decline in the price of nickel, a discount rate of 12% would still show that a minimumly satisfactory return would be achieved. Conversely, should the price of nickel rise substantially over the 1976 price, the impact would be highly favorable.

E. Variations in Assumptions of the Model

The deep ocean mining model may accommodate a great variety of assumptions as to capital structure, accounting practice, and tax treatment, in addition to the operational and equipment options examined in Chapter V. This section examines the impact on economic return of changes related to scheduling, operational options, and several other assumptions relating to financial or accounting practice and to taxation.

1. Delays

To provide an idea of the impact on economic return of delay, several were introduced into the baseline project's life. Figure VI-17 shows the effect of both a one year and a two year

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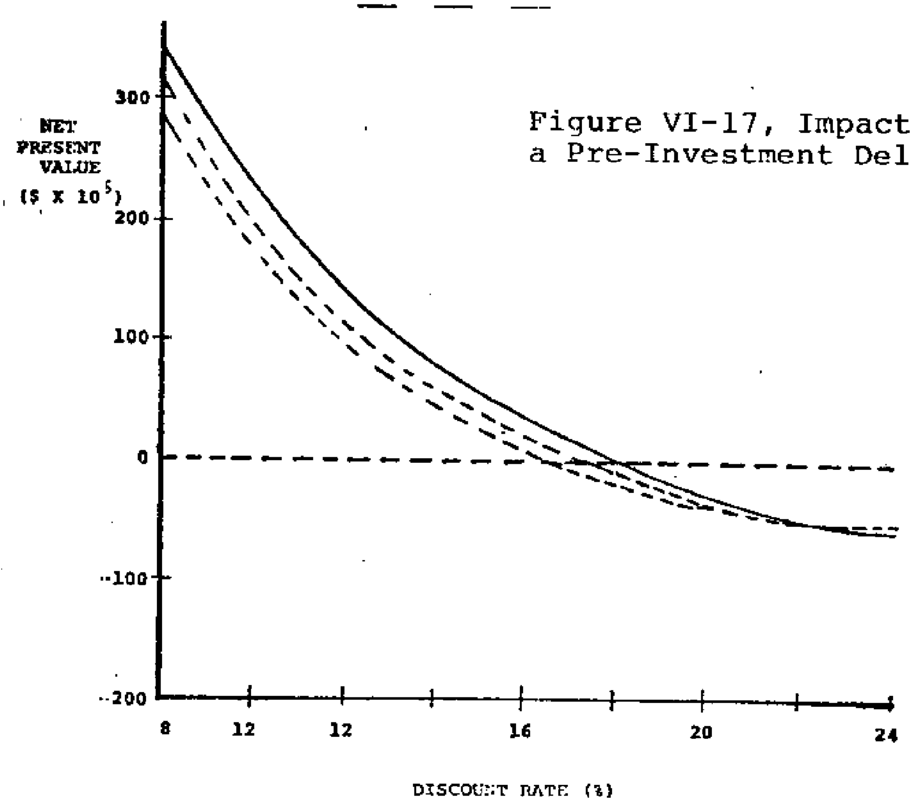

Figure VI-17, Impact of a Pre-Investment Delay

	Baseline	Delay = 1 Year	Delay = 2 Years
IROR (%)	18.14	17.53	17.01
Simple Payback (years)	5.4	5.4	5.4

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delay at the pre-investment point.

Next, similar one year and two year delays were introduced before operations begin. These results are shown in Figure VI-18.

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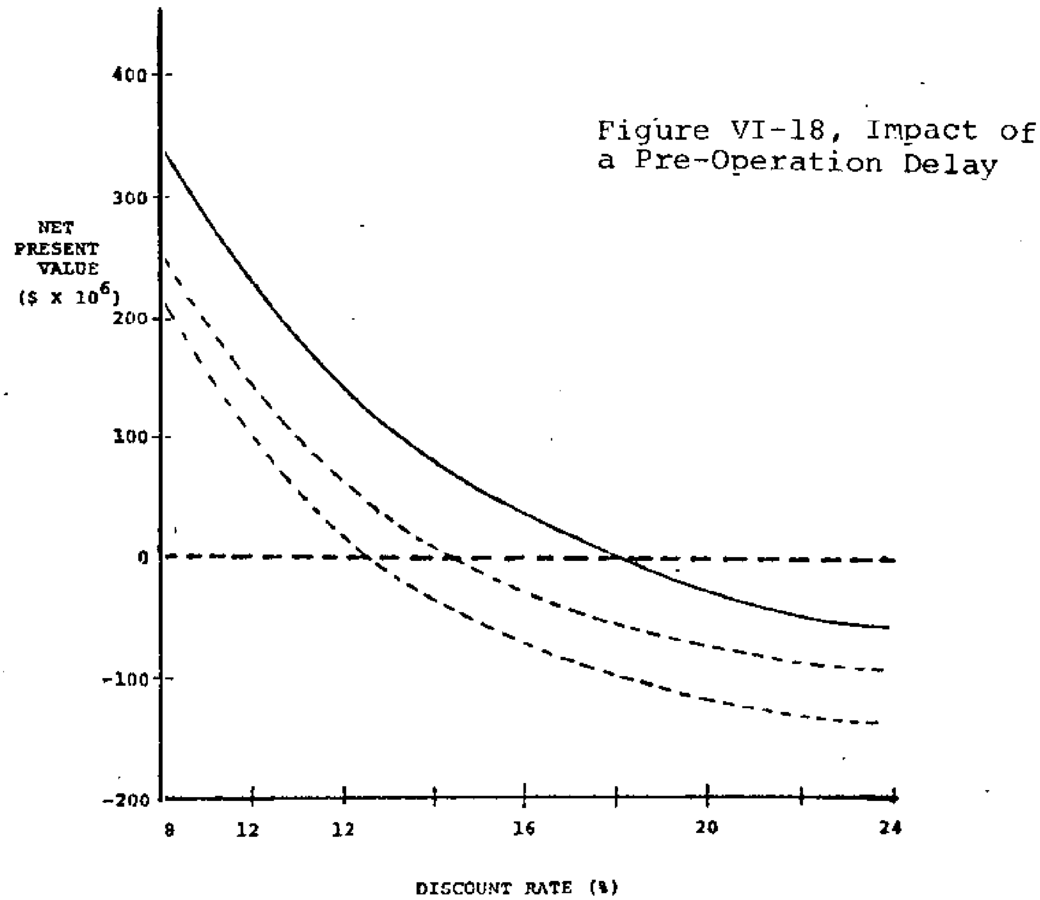

Figure VI-18, Impact of a Pre-Operation Delay

	Baseline	Delay = 1 Year	Delay = 2 Years
IROR (%)	18.14	15.16	12.95
Simple Payback (years)	5.4	5.2	5.4

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And finally, one year delays and two year delays at each point were introduced, with the results indicated in Figure VI-19.

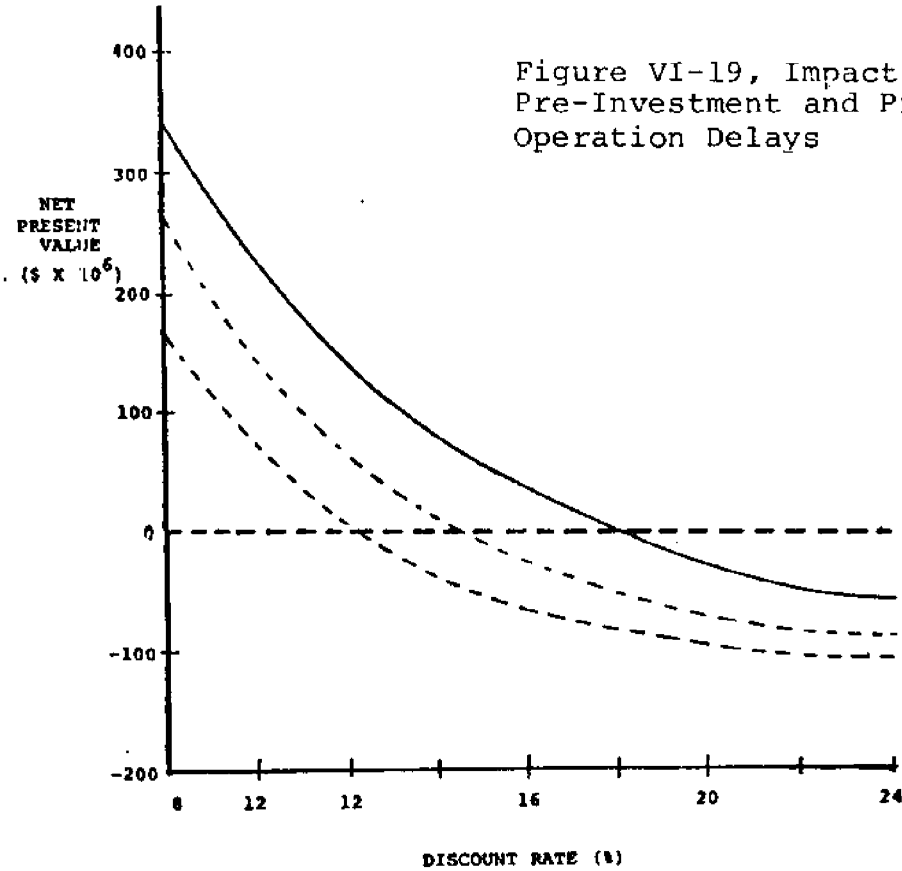

Figure VI-19, Impact of Pre-Investment and Pre-Operation Delays

	Baseline	Delay = 1 Year	Delay = 2 Years
IROR (%)	18.14	14.77	12.28
Simple Payback (years)	5.4	5.3	5.8

The results suggest that a delay once the project has started, i.e., after completion of the investment period and prior to commencement of recovery operations, reduces the economic return much more than one before the investment period. And, logically, the longer the delay, the greater the impact. The analysis confirms the observation that delays, regardless of cause, have significant unfavorable impacts on large complex projects such as an ocean mining venture. The delay phenomenon is addressed in a real life setting, the impact of delay in enabling legislation, in the next chapter.

2. <u>Skewed Capital Investment</u>

The effects of two alternate assumptions concerning capital investment are also examined. The baseline evaluation assumes that capital expenditures are evenly distributed over the investment period. However, another reasonable investment pattern assumes early, lesser expenditures being made for land and site development, followed by larger outlays for capital equipment as scheduled production operations approach. The impact of assuming a four year investment period with annual capital allocations of 5%, 15%, 45% and 35% was assessed. The effect is to lower the internal rate of return by 0.69 points and to increase payback .1 years to 5.5 years. The associated drop in NPV is shown in Figure VI-20.

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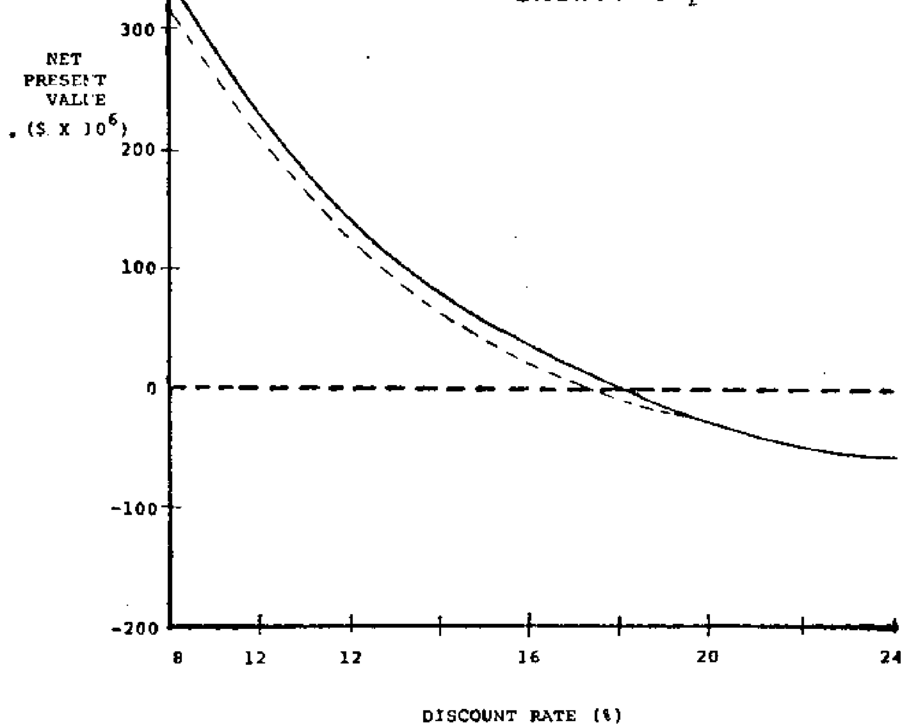
Figure VI-20, Impact of Skewed Capital Investment



	Baseline	Skewed Capital Investment
IROR (%)	18.14	17.61
Simple Payback (years)	5.4	5.5

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3. Escalation

To illustrate the effect of a general rise in the average price level of all goods and services, evaluation of the baseline conditions was repeated with the inclusion of an annual escalation rate of 6%. A uniform rate was selected to demonstrate that the effects of escalation should not affect project analysis conclusions.[2] Net present value and internal rate of return should be approximately the same as that determined under constant dollar analysis.

The results appear to confirm the hypothesis. Summarized in Figure VI-21, the analysis shows only a minor change. However, the movement in the same direction of both baseline IROR and simple payback invites further examination.[3]

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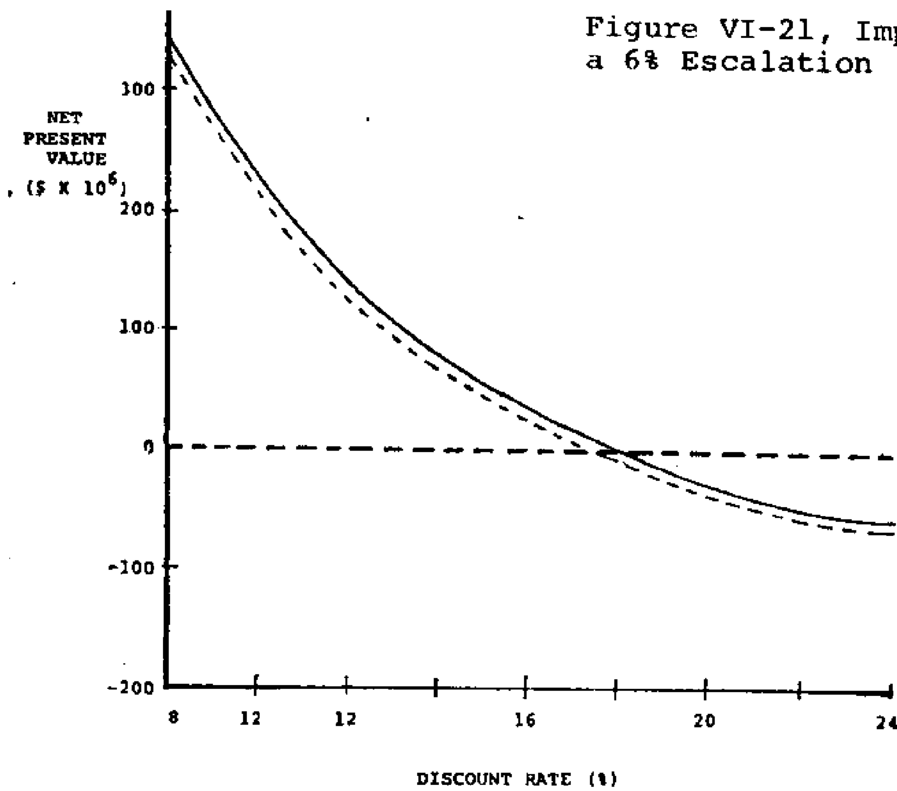
Figure VI-21, Impact of a 6% Escalation



	Baseline	6% Escalation
IROR (%)	18.14	17.99
Simple Payback (years)	5.4	4.4

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4. Exploration Program

The assumptions used in the analysis of the exploration program have an effect on the profitability of the ocean mining project due both to the magnitude of the exploration expense and to the scheduling of the expense during the project lifetime.

In the baseline model the entire minesite is explored concurrently with the first two years of the capital investment period. The effect of the exploration expense on profitability may be reduced by scheduling the program over a longer period. The longer exploration period would result in a higher total cost for the program, but the IROR would increase due to the postponement of most of the exploration expense.

In Chapter V the sensitivity analysis of variables in the cost estimation section of the model indicated that the total exploration expense is sensitive to the daily charter rate of the research vessel. As new and sophisticated equipment for analysis and remote observation of nodule deposits is developed and installed on research ships, the cost of chartering such vessels will rise, resulting in an increase in total exploration expense and a reduction in the profitability of the project.

The ocean mining model has been tested to determine the total exploration expense and the project's IROR for exploration periods of two, ten and 20 years and for charter rates of $5,000, $10,000, and $15,000 per day.[4] The results are presented in Table VI-4.

Table VI-4, Effects of
Variations of Exploration Parameters

(Total Exploration Expense, in millions of dollars, is in bold type, and Internal Rate of Return (IROR), in %, is in Italics.)

Length of Exploration Program (years)	Research Vessel Charter Rate (dollars/day)		
	$5,000	$10,000	$15,000
2	**$16.4** *18.14%*	**$30.6** *17.47%*	**$44.8** *17.05%*
10	**$19.1** *18.32%*	**$32.3** *18.06%*	**$47.4** *17.58%*
20	**$22.4** *18.39%*	**$36.6** *18.21%*	**$50.7** *18.03%*

The values of IROR for the nine combinations of exploration period and charter rate cover a range of 1.34%, from a low of 17.05% for a charter rate of $15,000 per day over a period of two years to a high of 18.39% for a charter rate of $5,000 per day over a period of 20 years.

5. U.S. Construction and Crews

As indicated in Chapter V, the existence of a U.S. preference requirement pertaining to vessel construction and crews will raise capital and operating costs. The impact on economic return under the assumptions set out in Chapter V is to lower the IROR from 18.14% to 16.26%. (Comparable figures for foreign versus U.S. construction and crews, using the alternative labor cost data set out in Chapter V are 18.56% and 16.97% respectively.)

6. Debt Structure

The role that debt plays in the roughly $500 million financing structure of a deep ocean mining operation may be critical to both the pace and size of the nodule industry's development. Financial and industry observers have suggested that the debt level might realistically rise to as much as two thirds of the capital requirements, so long as the cash flow provided sufficiently for coverage of interest and repayment of principal. This view reflected concensus at the NOAA Workshop held to review the working draft of this report.

In the baseline model, a middle ground 1:1 debt/equity ratio was used. Here the effects of both a 2:1 debt/equity relationship and of having no debt at all are shown in Figure VI-22. The advantage of the additional debt service which the

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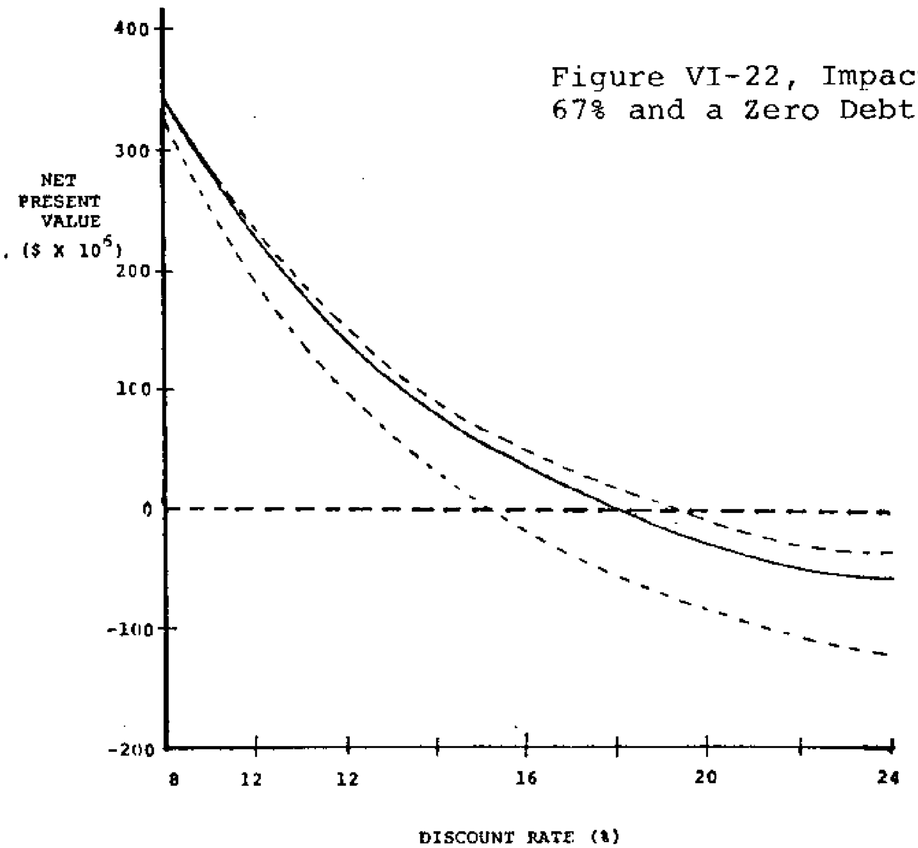

Figure VI-22, Impacts of a 67% and a Zero Debt Portion

	67%	Baseline	Zero
IROR (%)	19.53	18.14	15.41
Simple Payback (years)	6.2	5.4	4.0

— — —

cash flow allows is seen in the increase of the IROR to 19.53% and the increase in net present value at the different discount rates. The slightly more than four point IROR contrast between having no debt and having a two-thirds debt portion is important, if new legislative provisions are required in order that deepsea mining attract investment capital. This issue will be raised again in Chapter VII.

In Chapter III E, it was noted that the manner of loan repayment could affect project profitability. The method used in the baseline evaluation assumed that the loan was repaid in equal annual installments. In a comparative evaluation, the effect of requiring equal principal repayment of the debt, with interest payable on the unpaid principal balance, was determined. Under this condition, IROR was reduced to 17.82% and the payback period lengthened to 5.7 years.

7. Capitalization of R&D and Exploration Expenditures

If the research, development and exploration expenditures associated with the project are capitalized rather than expensed, the economic return for the project is lowered. Near term cash flows are reduced as a result of the loss of operating tax loss credits, not compensated for by the capitalized write-offs. Internal rate of return declined approximately a third of a percent to 17.74% and the payback period increased 1.4 years to 6.8. These results are summarized in Figure VI-23.

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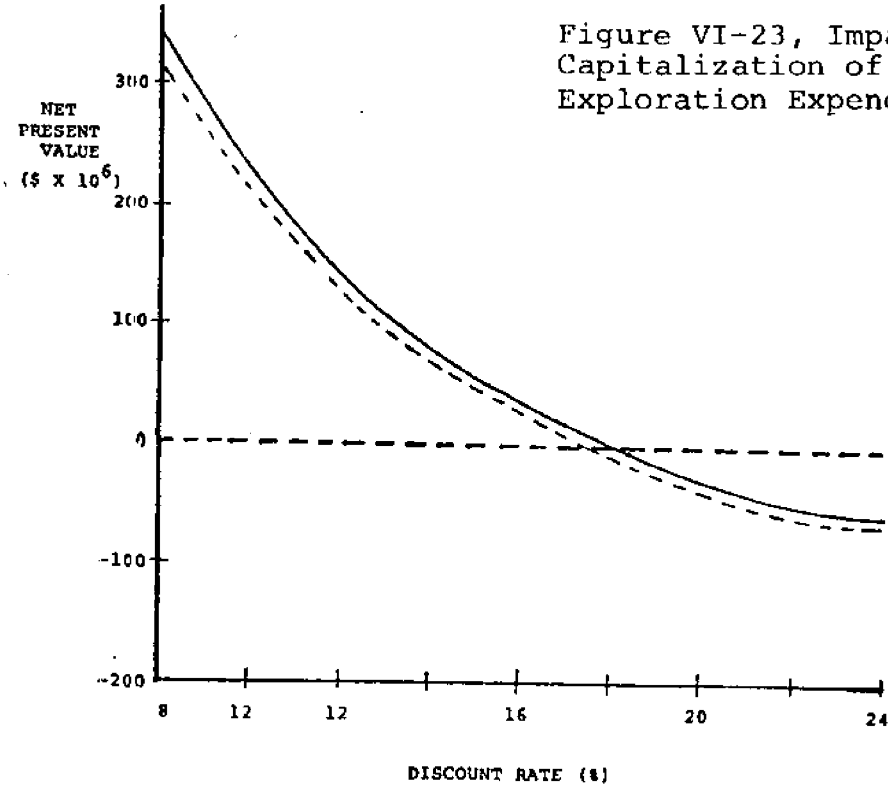

Figure VI-23, Impact of Capitalization of R&D and Exploration Expenditures

	Baseline	Capitalization of R&D and Exploration Expenditures
IROR (%)	18.14	17.74
Simple Payback (years)	5.4	6.8

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8. Depreciation

The model has the capability to compute depreciation by three methods. In the baseline model, declining balance with conversion to straight line is used because it is the most likely used of the available methods.

In many studies, however, the depreciation is calculated by the straight line method. Straight line depreciation is computed in equal annual installments over the depreciable life of the investment, so this method is the most suited for manual computation. It is often used in preliminary calculations of profitability. As indicated in Figure VI-24, use of the straight line method reduces the IROR to 17.68%, and reduces the indicated net present value sums somewhat. It also increases the payback period slightly.[5]

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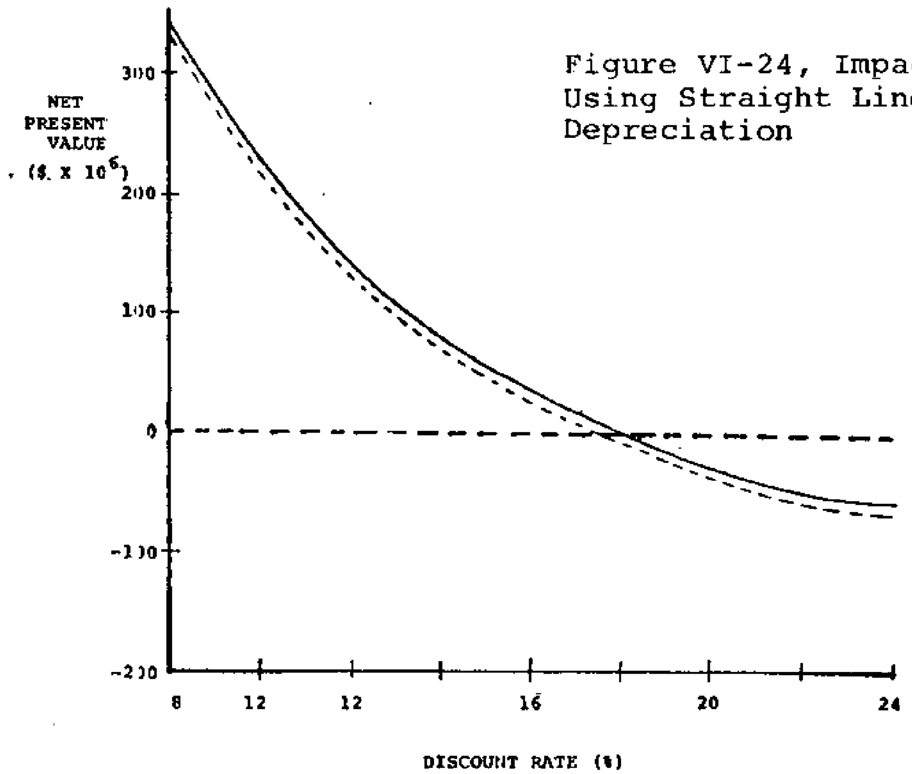

Figure VI-24, Impact of Using Straight Line Depreciation

	Baseline	Using Straight Line Depreciation
IROR (%)	18.14	17.68
Simple Payback (years)	5.4	5.9

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9. Depletion

Whether or not a percentage depletion allowance is allowed mineral deposits taken from the ocean floor, and if so, at what percentage rate, are probably questions which will be settled by Congress, for reasons discussed in Appendix F. Assuming a depletion allowance applies, the rate would likely be either the 14% metal mines allowance under 2 USC 613 (1)(B)(3) or the more favorable 22% rate for cobalt, nickel, and manganese and

15% for copper provided for deposits within the U.S. under 613 (1)(b)(1)(B) and (1)(b)(2). The baseline model applied the first or straight 14% rate. Figure VI-25 shows the effect of treating the minerals as deposits within the U.S., as provided by the current version of HR 3350, and of providing no percentage depletion.

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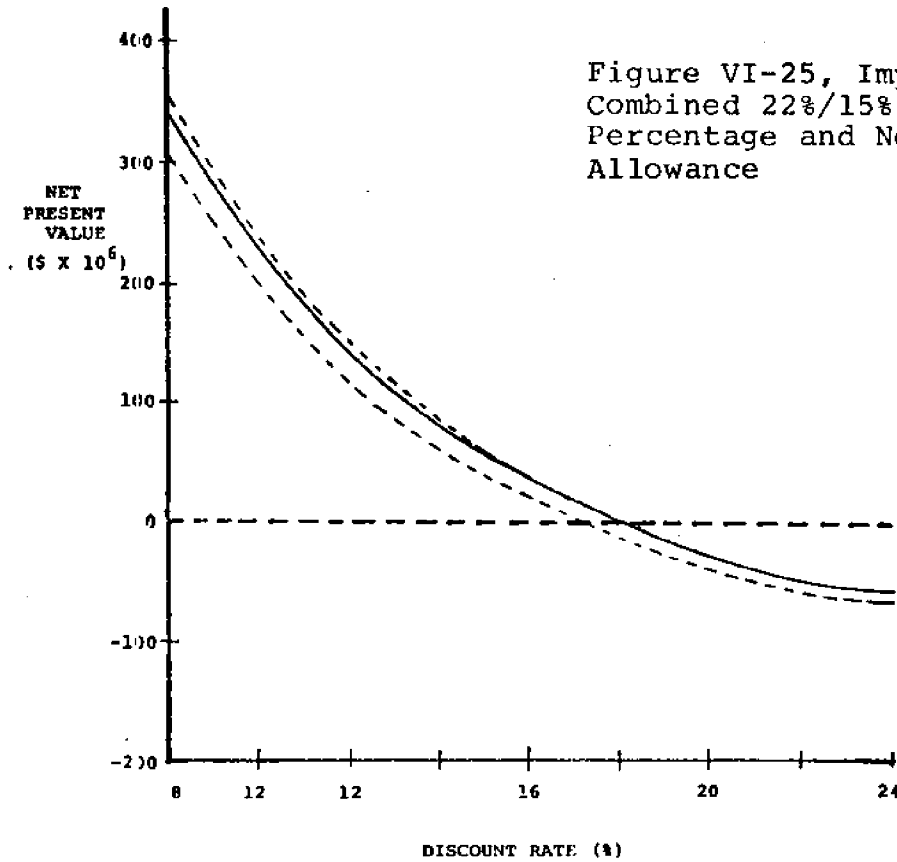

Figure VI-25, Impact of Combined 22%/15% Depletion Percentage and No Depletion Allowance

	22%/15%	Baseline	No Depletion
IROR (%)	18.26	18.14	17.34
Simple Payback (years)	5.4	5.4	5.9

— — —

The impact of the more favorable rate raises the IROR less than one half percent over the baseline model, while the denial of depletion lowers the IROR by about the same amount.

The indicated difference in IROR between no depletion and the most favorable rate is .9%.

Assumptions concerning depletion, depreciation and other parameters varied in this section may constitute future policy decisions which legislators and government officials will confront. Additional policy issues are examined in the next chapter.

Chapter VI Notes

1. Two variations in the mining sector that affect both capital and operating costs have been suggested by industry sources. First, Mr. Ed Dangler of Lockheed Missiles and Space Company noted that the drag coefficient of a nodule is less than that of a smooth sphere, and that the use of a higher drag coefficient in the model would result in a slight decrease in costs. The model was tested with a 50% increase in the drag coefficient to a value of .75. This resulted in a savings of $.28 million in capital cost and $1.5 million in operating cost. The IROR for the model increased by .02% to 18.16%.

   Second, Mr. Steven van der Veen of Kennecott Copper Corporation pointed out that the propulsion power requirement of the mineship appeared to be low. This was tested in the model by increasing the propulsion power requirement by a factor of four. The results of this test showed an increase of the total ship power requirement by 84% to a value of 31 thousand horsepower. The capital cost of the system increased by $5.7 million, the operating cost increased by $3.2 million, and the IROR of the project decreased by .57% to a value of 17.56%.

2. Stermole, Franklin A., <u>Economic Evaluation and Investment Decision Methods</u>, 1974, Golden: Investment Evaluations Corporation, p. 165.

2. Stermole, Franklin A., p. 165.

3. The presence of any difference at all may arise for a variety of reasons. Some tax deductions or credits (depreciation, interest, investment credits, loss carry forwards, etc.) are stated in dollar terms for the year in which the expense occurs, not in dollar terms of the later year in which the tax benefit is taken. The net annual cash flow is consequently higher than it would be if no escalation is assumed.

4. Suggested in personal communication with Mr. Ed Dangler, Lockheed Missiles and Space Company.

5. The use of the sum-of-years-digits method of depreciation results in an increase of .2% in IROR to a value of 18.34%.

Chapter VII. ANALYZING U.S. LEGISLATIVE PROPOSALS

A major use of the model, stated at the outset of this report is to provide insight into issues relating to the international and national agreements for the governance of deep ocean mining now under serious consideration in the Law of the Sea Conference and the U.S. Congress. This chapter provides six initial analyses aimed at this goal.

A. Desirability of Legislation

The first three analyses concern the desirability of U.S. legislation. In no way do they singly or collectively purport to answer the ultimate question of desirability of Congress's enacting a bill. Rather they provide some insight into three distinct pieces of the problem.

1. Contributions to National Income

The gross benefit to the national income made by a deep seabed mining operation such as that represented by the baseline model is approximated in this study by the sum of the discounted taxes distributed to the federal, state, and local governments and the discounted value of the profits distributed to the owners of the mining p ject. The discount rate used for both the public income, represented by the tax payments, and the private income is the social rate of discount defined by the government.[1] This discount rate is a representation of the relative value of present and future income to the nation as a whole. A rate of 10% has been used in the baseline model to illustrate the contribution to national income of the mining project.

For the baseline model the cumulative discounted contribution to national income over the entire life of the project is approximately $490 million. Of this contribution to national income approximately $260 million is received through taxes and the remainder is distributed to the owners of the mining project. These numbers are based on the assumption that the profits are dsitributed solely within the United States. Further, the numbers do not include benefits to the nation resulting from changes in the balance of payments, nor from possible decreases in metals prices, most notably cobalt.

An additional analysis was made to determine the effect on national income and on total tax payments of a tax system that disallows depletion allowance for the ocean mining project. For this case the total contribution to national income remained unchanged at approximately $490 million, but the distribution was changed by an increase of about $26 million in total discounted tax payments and a corresponding decrease in the distribution of benefits through the private sector.

2. Facilitation of Debt Financing

A long standing argument for U.S. domestic legislation on ocean mining is that it would be beneficial, and perhaps necessary, in raising debt financing from financial institutions. In Chapter VI, section E-6, an analysis showed the advantage of obtaining a maximum prudent debt component over having no debt at all. The difference for the baseline model was 4.12 percentage advantage in IROR and 2.2 year change in payback period. For the associated changes in NPV at different discount rates, see Figure VI-22.

3. Impact of Delays

U. S. industry appears technologically capable of moving into the development phase of deep ocean mining. Thus far, however, the argument within the U.S. government that the Law of the Sea Conference negotiations should take precedence over the passage of U.S. legislation has prevailed.

Assuming that this position continues, the commencement of any deepsea mining project would be dependent upon the creation and enactment of international institutional arrangements such as the proposed international seabed resource authority (ISRA). The time required to put the new institutional mechanisms in place will add several years to the commencement date of deep seabed mining. Under the most favorable conditions of negotiation and ratification of the complex situation, the earliest mining operation under ISRA is likely to get underway by 1984. Assuming that arrangements under an ISRA would provide for a private industry oriented project such as the one under consideration in this study, the delay introduced by not passing U.S. legislation enabling earlier deepsea mining can be measured by the time gap between the two sets of assumptions. The effect of a time gap of four years between the completion of R & D and the beginning of capital investment is shown in Figure VII-1.

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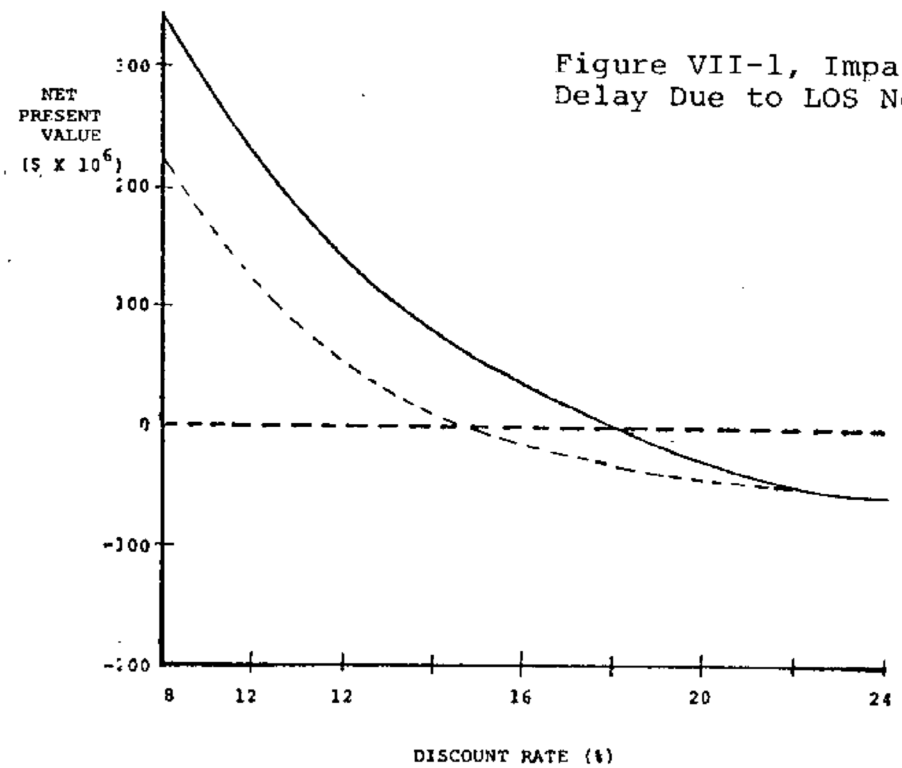

Figure VII-1, Impact of Delay Due to LOS Negotiations

	Baseline	With Delay
IROR (%)	18.14	15.25
Simple Payback (years)	5.4	6.1

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In terms of the analysis of one project, one measurement of the cost of this delay is the difference between the net present values determined for each of the two scenarios. This difference also can be seen in Figure VII-1. One practical effect of this difference is the consideration likely to be given to the project by the industry consortia as they consider whether to continue preliminary investment commitments to deep seabed mining. It may be that industry will continue to make investment into the R & D period on speculation that they will at some point be able to go ahead, thereby diminishing the delay gap hypothesized here. On the other hand, the prospect of delay inevitably lowers the attractiveness to management decision-makers today who are considering whether to continue investing in deep seabed mining or to seek alternate uses of their funds.

The above analysis clearly does not take into account either the strategic evaluation to the United States of having a deep seabed mining resource or the minerals involved. Nor does it consider the possible consequences such legislation would have upon the continued effort to arrive at an overall LOS treaty, or the very uncertain reaction of members of the international community. But it does provide, on a project basis, some indication of the cost to the overall attractiveness of the project of a policy choice to pursue the international solution at the expense of a domestic one.

B. Policy Options

If the United States does enact deep ocean mining legislation, many policy decisions will confront legislators or the regulators assigned implementing responsibility. Brief analyses of the following three suggest the applications in which the model developed in this study might be used.

1. U. S. Bottoms and U. S. Crew

One illustrative policy issue is the treatment in legislation of the national status of the mining system's transport vessels and their crews. There appear to be at least three options:

-- To provide no restriction or economic incentive which would affect the mining system operators' choice as to where the transport ships will be constructed and as to the nationality of their crews;

-- To specify by legislation or by regulatory interpretation that the ships be constructed in the U.S., carry U.S. crew and be considered in the coastwise trade; or,

-- To specify by legislation or by regulatory interpretation that the ships be constructed in the U.S., carry U.S. crew, but be considered in foreign trade, thereby raising the possibility of eligibility for construction and operational differential subsidies.

a) Absence of restriction or incentive

Both U.S. construction and operational costs are markedly higher than comparable foreign costs. In sub-section D-3 of Chapter V, the capital cost differential was estimated to be $34.1 million. The operating costs differences were estimated to be $6.3 million. The effect on the project's economic return of these differentials was noted in Chapter VI, sub-section E-6. U.S. construction and crew assumptions were found to decrease the IROR% to 16.26% and lengthen the simple payback period 1.1 years to 6.5. Those results are presented graphically in Figure VII-2.

It was because of these higher costs that in the baseline model foreign construction and crew were used. It was assumed that the mining system operators would opt for the lowest costs, absent any restriction or compensating incentive.

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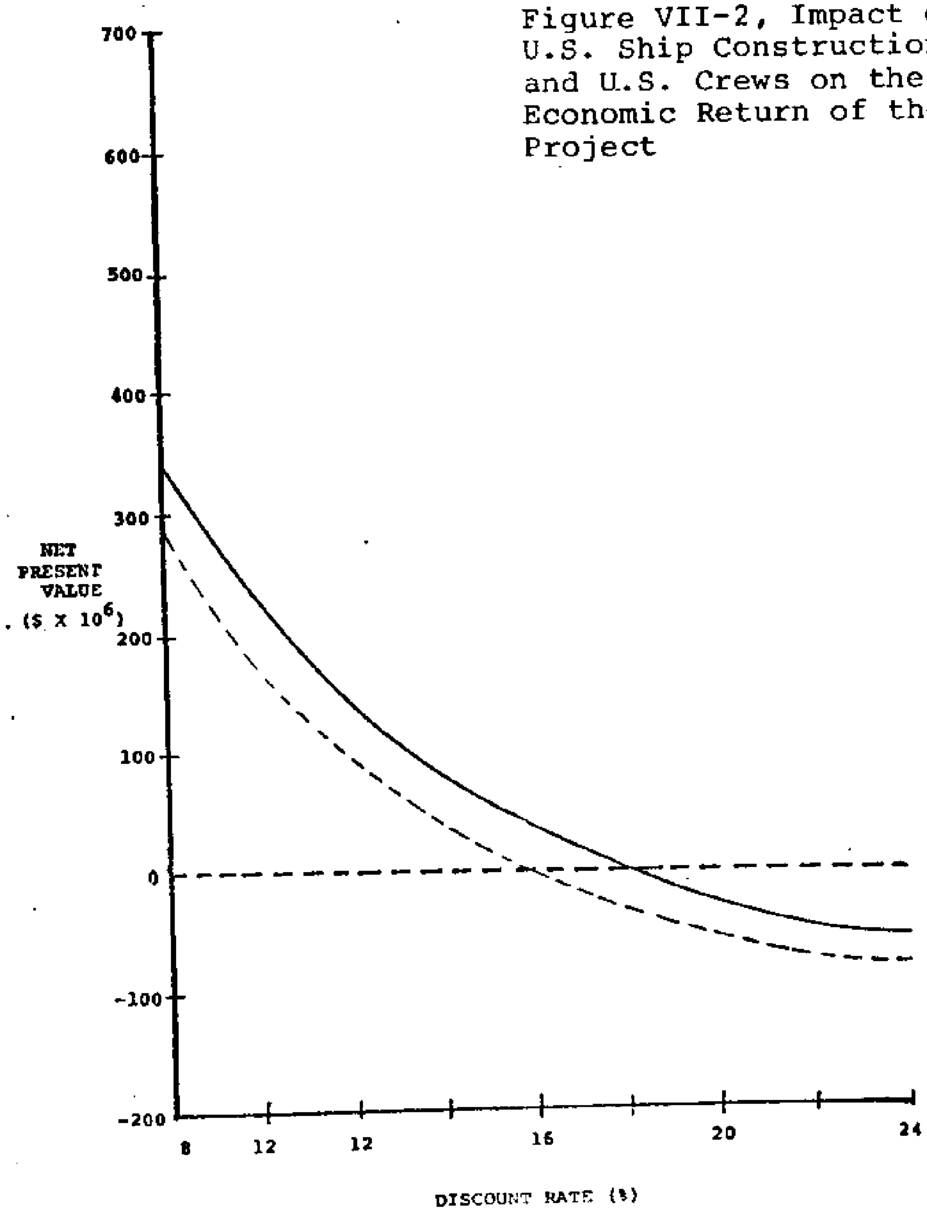
Figure VII-2, Impact of U.S. Ship Construction and U.S. Crews on the Economic Return of the Project



	Baseline	American Construction and Crews
IROR (%)	18.14	16.26
Simple Payback (years)	5.4	6.5

— — —

b) U.S. construction and crew in the domestic trade

It may be in the economic and strategic policy interests of the United States, however, to require U.S. built ships and U.S. crews. Congress could achieve this goal by classifying the transport ships as being in the domestic trade, as is done by §14B of H.R. 3350. Ships in the domestic trade are required to be of U.S. registry and consequently carry U.S. crew,[2] and to be of U.S. construction.[3] The cost in terms of economic return on the investment is that indicated in Figure VII-2, against which benefits to the economy such as wages added as additional shipyard or seamen's jobs could be compared. A midway policy position, requiring U.S. registry and crews, but not characterizing the transportation as coastwise would permit foreign construction so long as the ships are owned by U.S. citizens.[4]

c) Foreign trade characterization

Still another option would be to require U.S. construction and crew, but to characterize the transportation system as being in foreign trade, and its owners as eligible to apply for construction and operating differential subsidies. The effect would be substantially to wipe out the gap represented in Figure VII-2, with an equivalent economic burden (plus transaction costs) being assumed by the U.S. government. However, several problems appear to exist.

Under the Merchant Marine Act of 1936 (46 USC 1101-1294), as amended, provisions were made to grant construction and operating subsidies to U.S. shipping operators so that the U.S. shipping industry would not be at a disadvantage compared to lower cost operations of competing nations.

Direct differential subsidies were placed under Title V of the act. These subsidies cover both capital and operating costs. (Title XI of the act established a system of ship mortgage guarantees.)

Construction differential subsidies take two different forms. In the first, the shipowner or operator obtains a bid from a domestic shipyard. It also receives a bid or makes an estimate for construction in a foreign shipyard. The domestic and foreign costs are then presented to MARAD along with the plans for the ship. If the ship plans and costs are acceptable, MARAD can grant a direct subsidy in the form of payment to the contracting U.S. shipyard. The subsidy is the difference in cost between the foreign bid and the actual contracted bid.

In the second method, MARAD then takes responsibility for obtaining competing bids from American shipyards. These bids are then checked against foreign construction costs for a comparable ship.

The amount of subsidy paid has been on a sliding scale and is, as of 1975, limited to 35% of the contract price.

Operating differential subsidies work much the same as the construction differential subsidies. The subsidy is the difference between the cost of maintaining a foreign crew and an American crew. The operating subsidy also compensates for insurance on hulls and equipment (this provision is being phased out), and for maintenance and repair costs and subsistence.

For a ship owner to qualify for subsidies a number of conditions must be satisfied, including the following:

-- Plans and specifications must meet requirements of foreign trade of U.S., must be suitable for defense and able to aid in promotion and development of national commerce.

-- The applicant must possess the ability, experience and financial resources and other necessary qualifications for operating and maintaining the proposed vessel.

-- Granting of aid must be reasonably calculated to carry out effectively the purposes and policies of sub-chapter V, section 1151 of the act.

Significant to the statutory subsidy language is the term "U.S. foreign trade". "Foreign" is defined in terms unlikely to encompass an ocean mining operation as now envisioned. The act defines U.S. foreign commerce as commerce or trade between the U.S., its territories or possessions or Washington, D.C., and a foreign country. Furthermore, the Code of Federal Regulations, with regard to the Merchant Marine Act, section 1156, states that foreign trade shall be:

-- exclusively foreign trade

-- round world voyages

-- round trip voyages from U.S. west coast ports to European ports, including intercoastal ports of the U.S.

-- voyages in foreign trade in which the vessel may stop in or on an island possession of the U.S.

The act also includes as foreign, trade between U.S. ports and and the islands of Guam and Wake.

This language suggests that unless the wording or definitions were changed, nodule transport vessels would not be eligible for subsidies unless new legislation so specified.

2. Depletion Allowance

As suggested in Chapter VI, section D-2, the provision of percentage depletion allowance will most likely be decided by Congress. As indicated in that discussion, the projections of this model indicate a .46% advantage in IROR and a .5 year payback period reduction obtained by treating the minerals as U.S. ore for depletion purposes, as compared to providing for no percentage depletion.

3. Political Risk Coverage

One goal of the mining industry has been to obtain domestic legislation providing risk guaranty coverage of the diminishment of a company's investment as a result of treaty obligations undertaken by the United States subsequent to the company's embarking on an ocean mining venture. One possible purpose of this provision is to achieve a stable investment climate in order to attract investment capital. In the following analyses, the baseline model is used in a preliminary examination of the impact of risk guaranty provisions on a deep ocean mining project.

This study's examination of the effect of political risk provisions is conducted in three stages. The first stage of the examination is to determine the cash vlaue of the gauranty. The second stage is to use the calculated value of the guaranty in the calculation of the profitability of the mining venture when it is terminated prematurely. In the third stage the likelihood of premature termination is combined with the profitability calculations to illustrate the effects of uncertainty on the investment decision and the role of the risk guaranty in the decision. The three stages of the examination are conducted in sub-sections a, b, and c respectively.

The analysis is based on the assumption that the mining venture has no resale value on termination. This assumption is examined in sub-section d where the three stages of the examination described above are repeated for a specified resale value.

a) Computation of the values of the guaranty

Several forms of investment gauranty have been suggested in recent proposed legislation. This analysis considers three particular guaranty provisions. The first is based on the provisions of H.R. 9 (93rd Congress, 1st Session). The second and third are based on provisions suggested in H.R. 11879 (94th Congress, 2nd Session).

The provisions of H.R. 9 provide that the United States would reimburse the mining companies for any loss of investment due to requirements or limitations imposed by an international regime to which the U.S. becomes a party. In the computer model the cash value of the guaranty is calculated by taking the capital investment made by the time of termination and subtracting the amount of the capital investment recovered as depreciation, and the amount recovered by resale of the venture after it is terminated. As noted above, in this particular analysis, no resale value is assumed. These components of the guaranty are illustrated in Figure VII-3.

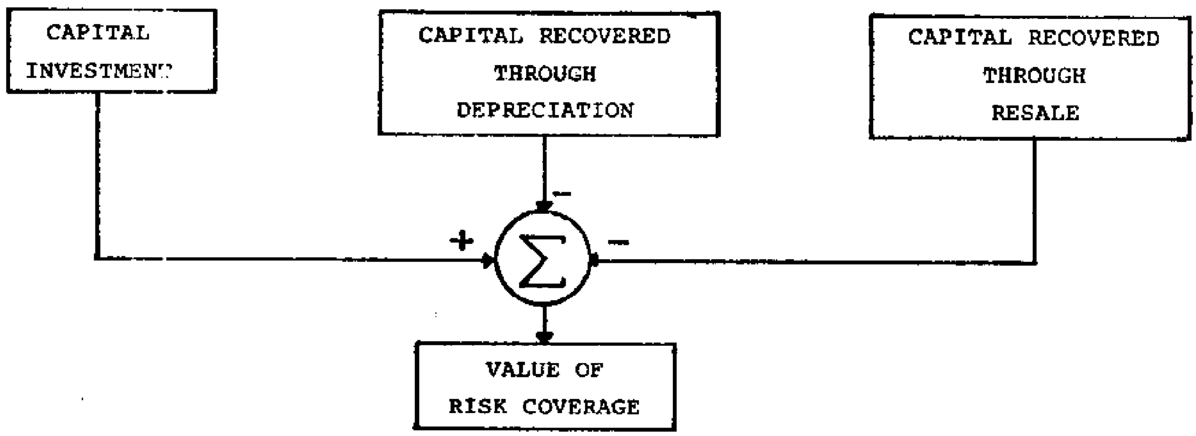


Figure VII-3

COMPONENTS OF RISK GUARANTY COVERAGE
AS PROVIDED BY H. R. 9

The guaranty provisions of H.R. 11879 are more limited than those of H.R. 9. Under the provisions, the mining companies are limited to protection of the expenses of the exploration program for the minesite until the government authorizes the companies to begin commercial recovery. Once this authorization is given, the value of the guaranty is decreased by the gross profits of the venture, in addition to the funds recovered as depreciation and from resale of the venture. The R&D and exploration programs, which are expensed in the early years of the project, are credited against future gross profits in the computation of the guaranty. The components of the guaranty provided by H.R. 11879 are illustrated in Figure VII-4.

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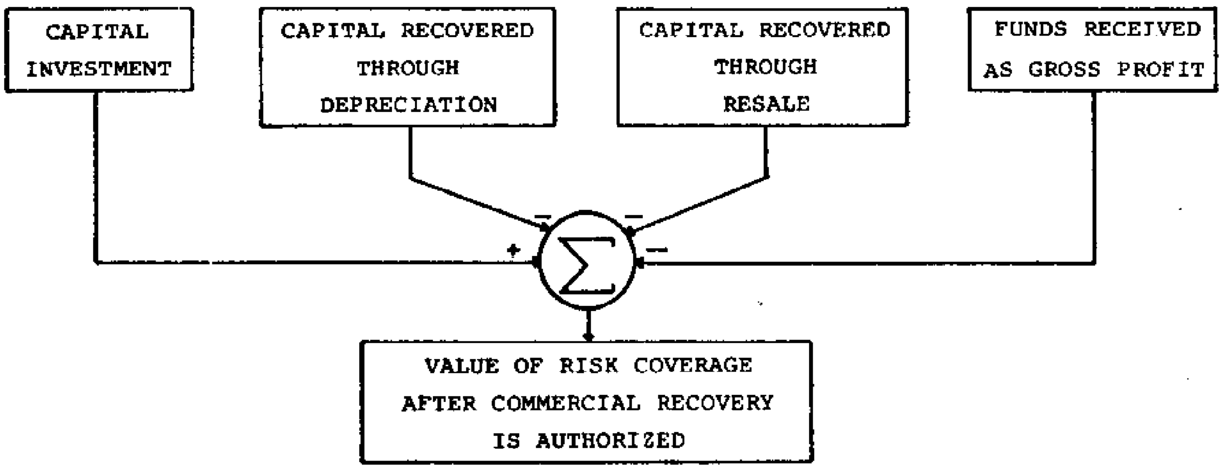

Figure VII-4

COMPONENTS OF RISK GUARANTY COVERAGE AS PROVIDED BY H.R. 11879

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For the first mining projects operating the deep seabed it may be possible to include some part of the cost of the mining system in the development cost of the minesite, since a full scale system has not been tested before.[5] In order to consider this possibility, two forms of the guaranty proposed in H.R. 11879 are considered. In the first case the entire cost of the mining sector is included as part of the development cost. In the second case the cost of the mining sector is totally excluded. This provides upper and lower bounds to the value of the gauranty under this proposal.

The values of the guaranty payments for H.R. 9 and H.R. 11879, which bracket the value of H.R. 3350 filed in 1977, are presented in Table VII-1.[5] The payments differ most notably after the beginning of commercial recovery in 1981. The value of the guaranty under H.R.9 gradually decreases as the company recovers its investment through depreciation. Since H.R.11879 guaranty is reduced by gross profit and depreciation the value of the guaranty is more quickly reduced. This reduction is expecially rapid because gross profits are calculated before depreciation is deducted, so that the value of the guaranty is reduced twice by depreciation, once explicitly and once as part of the gross profits.

b) Effect of guaranty provisions on project net present value

The effect of an investment guaranty on the profitability of the mining project can be illustrated by calculating the potential net present value of the project in the case of premature termination for each year during the planned lifetime of the project. The net present value of a project terminated at the end of any particular year (here termed the K'th year) includes the cumulative value of the annual discounted cash flows as well as the payment of all outstanding debt and the addition of whatever guaranty is received from the government. The value of all revenues, capital investment, and operating costs are discounted and included in the accumulated discounted cash flow. The value of the guaranty is discounted at the appropriate rate for the K'th year and added to the accumulated discounted cash flow. The remaining debt is also discounted from the K'th year and is subtracted from the sum of the accumulated discounted cash flow and the discounted guaranty.

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Table VII-1

Value of Investment Guaranty
in the Event of Project Termination

YEAR	H.R. 9	H.R. 11879 (with mining costs)	H.R. 11879 (without mining costs)
1976	0.0	0.0	0.0
1977	0.0	0.0	0.0
1978	164.4	39.4	7.4
1979	328.7	78.7	14.8
1980	493.1	110.6/493.1	14.8/493.1
1981	419.6	353.3	353.3
1982	357.5	141.2	141.2
1983	304.8	0.0	0.0
1984	260.2	0.0	0.0
1985	222.4	0.0	0.0
1986	190.1	0.0	0.0
1987	161.3	0.0	0.0
1988	135.5	0.0	0.0
1989	109.9	0.0	0.0
1990	84.6	0.0	0.0
1991	65.6	0.0	0.0
1992	46.5	0.0	0.0
1993	27.5	0.0	0.0
1994	8.5	0.0	0.0
1995	6.4	0.0	0.0
1996	4.2	0.0	0.0
1997	2.1	0.0	0.0
1998	0.0	0.0	0.0
1999	0.0	0.0	0.0
2000	0.0	0.0	0.0
2001	0.0	0.0	0.0
2002	0.0	0.0	0.0
2003	0.0	0.0	0.0
2004	0.0	0.0	0.0
2005	0.0	0.0	0.0

Note: In the year 1980 the multiple values of the guaranty under both versions of H.R. 11879 represent the value before and after the government authorizes the company to begin commercial recovery.

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These calculations are depicted in Figure VII-5.

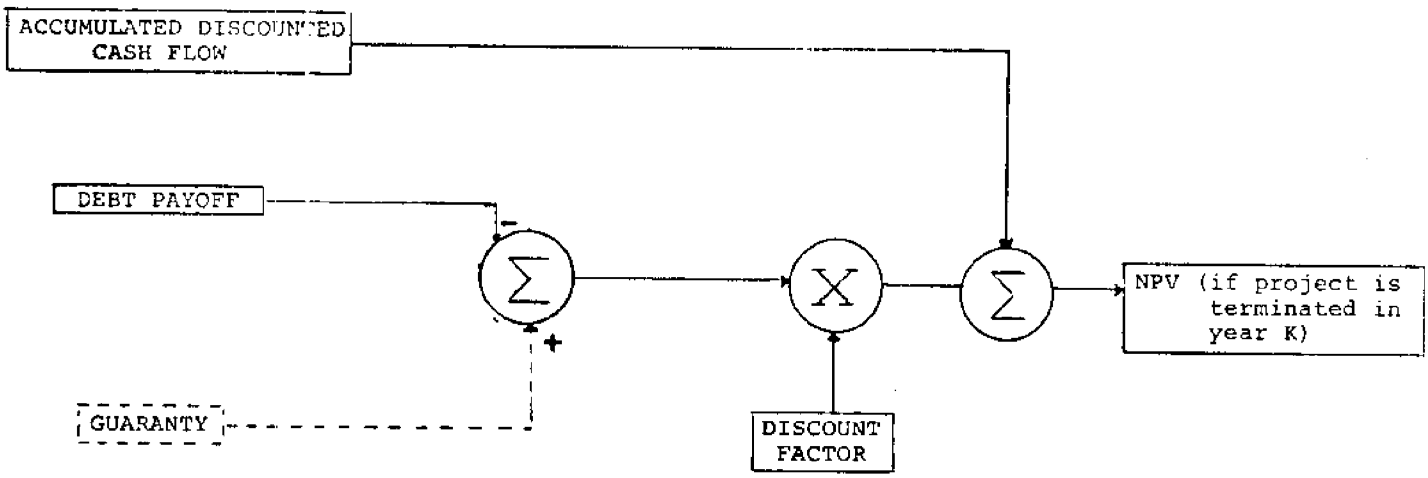

Figure VII-5
Calculation of Project Net Present Value
in Event of Premature Termination

The value of the potential Net Present Value of the mining project in the event of premature termination is calculated for the baseline case, without a guaranty, and for the three cases described in the preceding section. The calculations are based on a discount rate of 15% with no resale value and are reported in Table VII-2.

c) Effect of political risk on project profitability and cost to the government

The decision to invest in a project that has a range of possible outcomes should be based on both the potential profit or loss associated with each outcome and the likelihood of each outcome actually occurring. The potential profit or loss associated with premature termination of an ocean mining venture is examined in the preceding section. The second part of the basis for the investment decision, the likelihood of project termination in any year, is difficult to approach

Table VII-2

Potential Net Present Value of
Ocean Mining Project in Event of Termination
(Discount Rate Equals 15%)

YEAR	No Guaranty	H.R. 9	H.R. 11879 (with mining costs)	H.R. 11879 (without mining costs)
1976	-25.8	-25.8	-25.8	-25.8
1977	-48.2	-48.2	-48.2	-48.2
1978	-184.3	-60.1	-154.6	-178.7
1979	-300.0	-83.9	-248.5	-290.2
1980	-393.9	-112.0	-330.7/-112.0	-385.5/-112.0
1981	-321.8	-113.2	-146.2	-146.2
1982	-252.0	-97.5	-190.9	-190.9
1983	-195.0	-80.4	-195.0	-195.0
1984	-148.9	-63.9	-148.9	-148.9
1985	-113.5	-50.3	-113.5	-113.5
1986	-85.9	-38.9	-85.9	-85.9
1987	-62.7	-28.1	-62.7	-62.7
1988	-43.4	-18.1	-43.4	-43.4
1989	-27.0	-9.2	-27.0	-27.0
1990	-13.3	-1.4	-13.3	-13.3
1991	-2.3	5.8	-2.3	-2.3
1992	7.3	12.3	7.3	7.3
1993	15.7	18.3	15.7	15.7
1994	23.0	23.6	23.0	23.0
1995	28.7	29.2	28.7	28.7
1996	33.8	34.0	33.8	33.8
1997	38.1	38.2	38.1	38.1
1998	41.9	41.9	41.9	41.9
1999	45.2	45.2	45.2	45.2
2000	48.0	48.0	48.0	48.0
2001	50.5	50.5	50.5	50.5
2002	52.7	52.7	52.7	52.7
2003	54.5	54.5	54.5	54.5
2004	56.1	56.1	56.1	56.1
2005	57.7	57.7	57.7	57.7

Note: In the year 1980 the multiple values of the project under both versions of H.R. 11879 represent the value before and after the government authorizes the company to begin commercial recovery.

as an objective judgment, because the termination of an ocean mining operation for political reasons is a decision that would be made in the complex negotiations on the law of the sea. As an illustration of the effects of political uncertainty a hypotehtical distribution of termination probabilities has been chosen, and is depicted in Figure VII-6.

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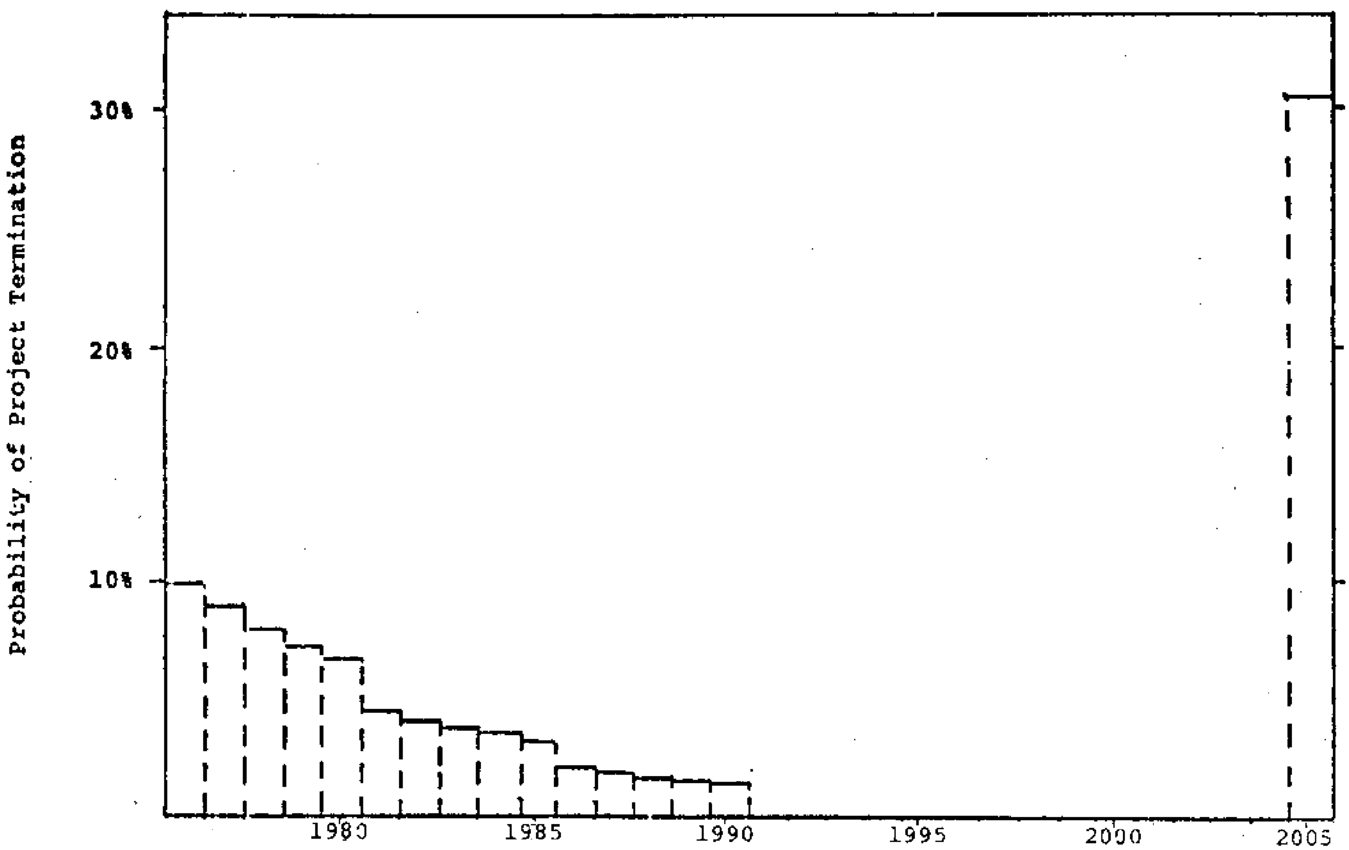

Figure VII-6

Probability of Termination During Project Lifetime

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The probability that the project is terminated during any year of the project lifetime is represented as a percentage indicated by a column for each year. For example, it was assumed that there was a 10% chance of termination in 1976, a 7% chance in 1980, a 5% chance in 1981, etc. If the project made it until 1990, it was assumed that it would continue until the end of its projected life. The column above the last year of the project, 2005, represents the probability that the project is completed as planned.

The decision to invest in an operation that has an uncertain outcome would normally be based on more factors than just the potential profit or loss and the likelihood of each outcome. In particular, the investor may consider whether the particular loss would represent a major portion of its assets. If so, the investor might tend to be more averse to the risk than if the loss were relatively small compared to its total assets.

For illustration purposes, however, the interaction of the two factors of profit and probability in the decision process can be shown by means of a single number that represents a weighted average of all possible outcomes. This average is taken by multiplying the net present value associated with a project terminating in each year by the probability of termination in each year and adding together the products for all of the years of the operation. The products for each year are shown in Figure VII-7. The contribution made by each year is represented by the volume of the box associated with the year. In the early years of the project, there is a high probability of termination and the NPV is negative, so a negative contribution is made to the weighted average. During the middle years of the project the probability of termination is zero so there is no contribution made to the average.

Finally, during the last year the NPV is positive and the probability of completion is high and a positive contribution is made to the average.

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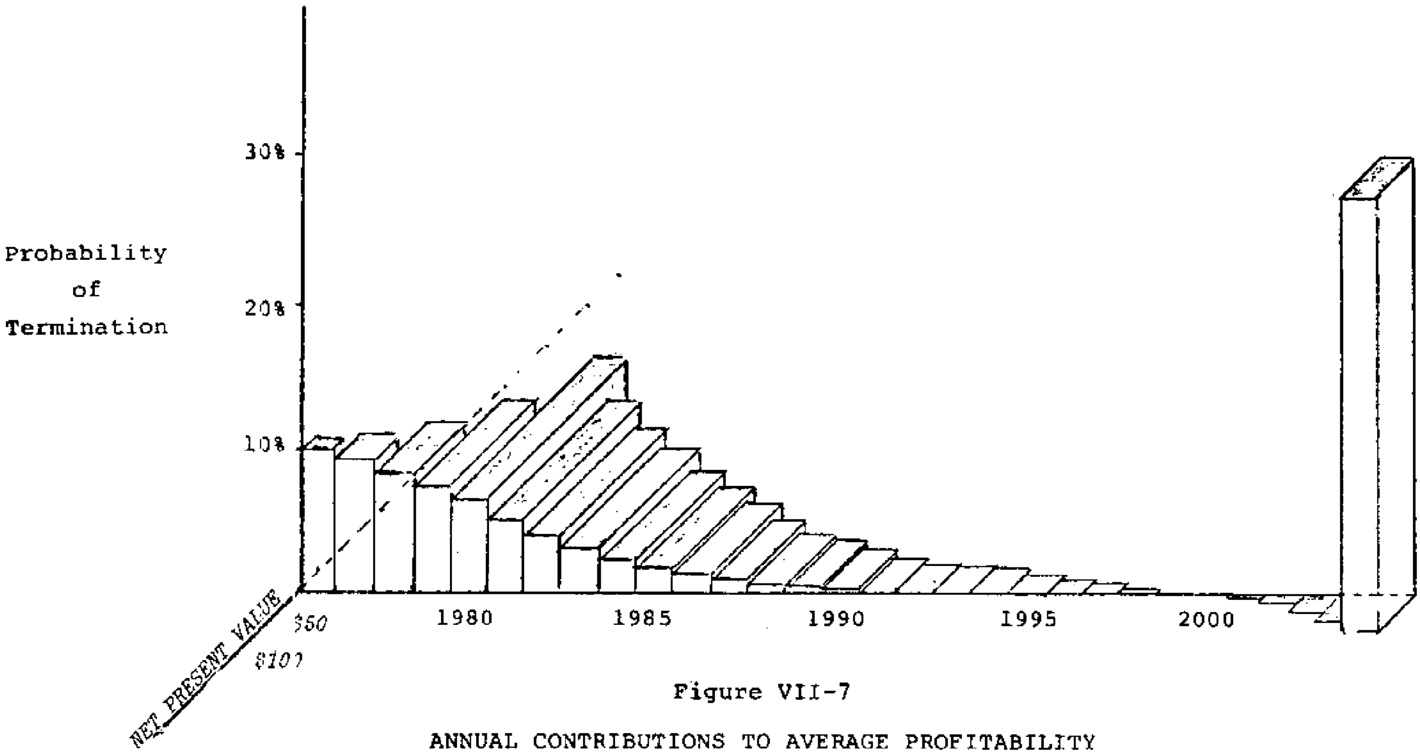

Figure VII-7

ANNUAL CONTRIBUTIONS TO AVERAGE PROFITABILITY
WHEN WEIGHTED BY PROBABILITY OF TERMINATION

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This averaging method has been applied to four cases: the baseline model without a guaranty, and the baseline model operating under the three guaranty provisions discussed above. These averages are reported in Table VII-3.

Table VII-3

The Effects of Guaranty Provisions on an Ocean Mining Project

	NPV when weighted by uncertainty and discounted at 15%
Baseline (without premature termination)	$57.7 million
Baseline (with possible premature termination)	-$96.9 million
Premature Termination	
Under H.R. 9	-$25.1 million
Under H.R. 11879 (development cost includes mining equipment)	-$73.3 million
Under H.R. 11879 (development cost excludes mining equipment)	-$84.9 million

The value of the baseline NPV is based on a 15% discount rate. The difference between the weighted NPV and the NPV without termination is dependent on the probability of project termination. The results, however, are illustrative of the effects of uncertainty on the decision to invest in ocean mining and the impact of investment guaranties on that decision.

The average NPV for the baseline model when weighted by uncertainty is -$96 million, which is about $150 million less than the NPV for the operation if it is assured of completing its planned lifetime. The weighted NPV is increased by about $70 million by the guaranty provided by H.R. 9, which indicates that such a guaranty can have an effect on the decision to invest when premature termination is possible. The guaranty provided by H.R. 11879 provides about 30% of the increase in weighted NPV that is attributed to the H.R. 9 guaranty if mining equipment costs are included in the minesite development costs, and about 17% of the H.R. 9 contribution if equipment costs are not included in the development costs.

d) Effect of resale value on project profitability in the event of termination due to political action

The termination of an ocean mining project due to provisions of an international treaty on the seabed may not result in a total loss of investment to the mining company. A complete mining system might be sold to whatever entity is allowed to mine the seabed. The resale value of a mining system is impossible to predict. In the preceding analysis the resale value is assumed to be zero. By modification of the equations for the value of the guaranty and for the potential net present value, the effects of a project resale value can be examined. In the following analysis the resale value of the project is estimated by interpolating values between a resale value of 50% of the capital investment at the beginning of the recovery period and the final salvage value of zero at the completion of the project. This assumption is shown in Figure VII-8.

The incorporation of resale value into the guaranty equations reduces the investment lost due to termination and, therefore, reduces the value of the guaranty.

The values of guaranties computed according to these equations, when calculated for a 50% resale value when new and zero salvage value at completion, are calculated according to H.R. 9 and H.R. 11879 both with and without mining equipment costs covered by the guaranty. These results are presented in Table VII-4. The incorporation of resale value into the NPV calculation shows that a guaranty under H.R. 9 provides coverage for seven years of commercial recovery and under H.R. 11879

Table VII-4

Value of Investment Guaranty
in the Event of Project Termination with
50% Resale Value at Completion of Investment

YEAR	H.R. 9	H.R. 11879 (with mining costs)	H.R. 11879 (without mining costs)
1976	0.0	0.0	0.0
1977	0.0	0.0	0.0
1978	164.4	39.4	7.4
1979	328.7	78.7	14.8
1980	493.1/246.5	110.6/246.5	14.8/246.5
1981	182.9	116.6	116.6
1982	130.7	0.0	0.0
1983	87.9	0.0	0.0
1984	53.2	0.0	0.0
1985	25.1	0.0	0.0
1986	2.8	0.0	0.0
1987	0.0	0.0	0.0
1988	0.0	0.0	0.0
1989	0.0	0.0	0.0
1990	0.0	0.0	0.0
1991	0.0	0.0	0.0
1992	0.0	0.0	0.0
1993	0.0	0.0	0.0
1994	0.0	0.0	0.0
1995	0.0	0.0	0.0
1996	0.0	0.0	0.0
1997	0.0	0.0	0.0
1998	0.0	0.0	0.0
1999	0.0	0.0	0.0
2000	0.0	0.0	0.0
2001	0.0	0.0	0.0
2002	0.0	0.0	0.0
2003	0.0	0.0	0.0
2004	0.0	0.0	0.0
2005	0.0	0.0	0.0

Note: In the year 1980 the multiple values for the value of the guaranty represent the value of the guaranty before and after the period of commercial recovery begins. Values prior to commercial recovery are based on zero resale value, which leads to the two values under H.R. 9 as the resale value increases to 50% of the investment at commencement of commercial recovery. The values of H.R. 11879 are also affected by the change in the limits of coverage after the government authorizes the company to begin recovery.

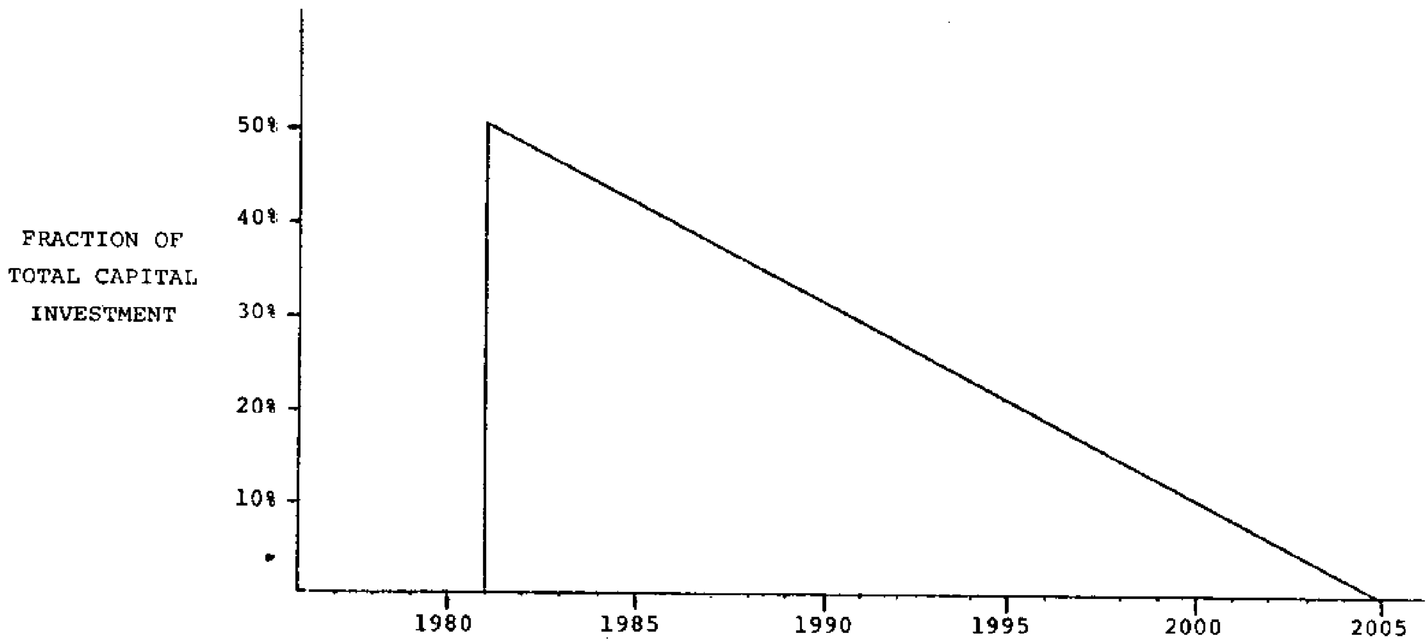

Figure VII- 8

RESALE VALUE AS A FRACTION
OF TOTAL CAPITAL INVESTMENT

there is coverage for only one year of commercial recovery. These periods are considerably less than the periods covered when resale value is not included in the calculation.

The potential net present value of the mining operation with resale value includes the discounted resale value with the value of the guaranty. This was depicted in Figure VII-8. For this calculation the discount rate is set at 15%. The values of the potential net present value when calculated for the baseline case without guaranty and for H.R. 9, H.R. 11879 with mining equipment costs included in the minesite development costs, and H.R. 11879 with mining equipment excluded for the minesite development costs are reported in Table VII-5. It can be seen that projects terminated in 1987 or later would have the same value regardless of the guaranty method.

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Table VII-5

Potential Net Present Value of
Ocean Mining Project in Event of Termination
with 50% Resale Value at Completion of Investment,
Zero at Completion of Project
(Discount Rate Equals 15%)

YEAR	No Guaranty	H.R. 9	H.R. 11879 (with mining costs)	H.R. 11879 (without mining costs)
1976	-25.8	-25.8	-25.8	-25.8
1977	-48.2	-48.2	-48.2	-48.2
1978	-184.3	-60.1	-154.6	-178.7
1979	-300.0	-83.9	-248.2	-290.2
1980	-393.9	-112.0	-330.7/112.0	-385.5/-112.0
1981	-204.1	-113.2	-146.2	-146.2
1982	-154.0	-97.5	-154.0	-154.0
1983	-113.4	-80.4	-113.4	-113.4
1984	-81.2	-63.9	-81.2	-81.2
1985	-57.4	-50.3	-57.4	-57.4
1986	-39.6	-38.9	-39.6	-39.6
1987	-24.6	-24.6	-24.6	-24.6
1988	-12.0	-12.0	-12.0	-12.0
1989	-1.4	-1.4	-1.4	-1.4
1990	7.6	7.6	7.6	7.6
1991	14.7	14.7	14.7	14.7
1992	21.0	21.0	21.0	21.0
1993	26.7	26.7	26.7	26.7
1994	31.7	31.7	31.7	31.7
1995	35.7	35.7	35.7	35.7
1996	39.2	39.2	39.2	39.2
1997	42.3	42.3	42.3	42.3
1998	45.1	45.1	45.1	45.1
1999	47.6	47.6	47.6	47.6
2000	49.8	49.8	49.8	49.8
2001	51.7	51.7	51.7	51.7
2002	53.4	53.4	53.4	53.4
2003	55.0	55.0	55.0	55.0
2004	56.3	56.3	56.3	56.3
2005	57.7	57.7	57.7	57.7

Note: In the year 1980 the multiple values of the project under both versions of H.R. 11879 represent the value before and after the government authorizes the company to begin commercial recovery.

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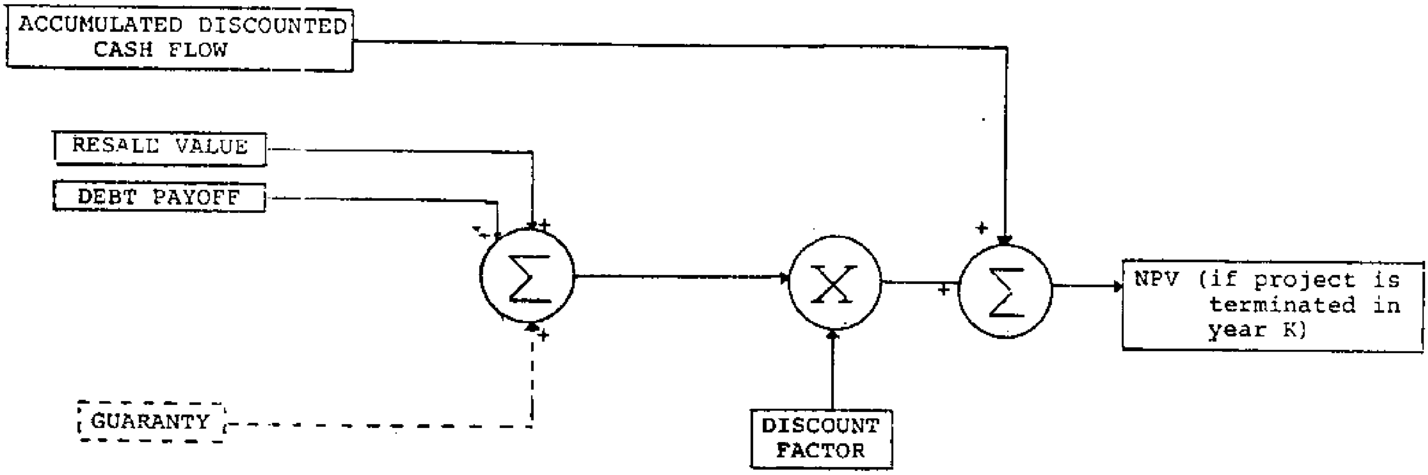


Figure VII-9
Calculation of Project Net Present Value in Event of Premature Termination (Including Resale Value)

The method of computation of the NPV weighted by the probability of termination is unchanged by the inclusion of resale value. The values of the weighted NPV are calculated for the baseline case 1) with no risk of termination, 2) with termination risk and no guaranty, and 3) with the three guaranty methods. The results are reported in Table VII-6.

The consideration of the resale value of the mining project results in an increase of about $20 million over the weighted NPV for the same operation with no resale value. The weighted NPV for an operation covered by H.R. 9 increased by only $.5 million, while the operations under H.R. 11879 increased by $9 million if equipment costs are included in the development costs and by $11 million if the equipment costs are excluded from the development costs.

Table VII-6

Effects of Guaranty Provisions on Profitability of an Ocean Mining Project with Resale Value

	NPV when weighted by uncertainty and discounted at 15%
Baseline (without premature termination)	$57.7 million
Baseline (with possible premature termination)	-$77.4 million
Premature Termination	
Under H.R. 9	-$24.7 million
Under H.R. 11879 (development costs include mining equipment)	-$64.5 million
Under H.R. 11879 (development costs excludes mining equipment)	-$73.1 million

Although the value of the NPV and the range between the NPV without termination and the value with the possibility of premature termination are dependent on the discount rate and the probability distribution used in the model, the results of the tests are illustrative of the effects of uncertainty on the mining operation. It is shown in the results that guaranties can have the effect of increasing the attractiveness of the investment when the operation is affected by possibility of premature termination. Also, the effect of resale value is most pronounced on the operation that has no guaranty, with less effect under the provisions of H.R. 11879 and almost no effect under the provisions of H.R. 9.

Chapter VII Notes

1. Devanney, J. W. III, The OCS Petroleum Pie, Sea Grant Report No. MITSG 75-10, 1975, Cambridge, Mass., p. 8.

2. 46 USC 221 as to officers and watchstanders.

3. 46 USC 11.

4. Ibid.

5. The exploration activities that are covered by the guaranty of H.R. 11879 are defined to include the sampling of the deposit "necessary for the design, fabrication, installation, and testing of equipment".

6. The guaranty provisions of H.R. 3350, submitted to the House of Representatives in 1977, provide that the value of the guaranty be reduced by the net after-tax profits of the mining operation. This provision provides a guaranty with a value between that for H.R. 9 and for H.R. 11879.

APPENDIX A, PROSPECTING AND EXPLORATION

I. Introduction

The identification and selection of a minesite for a deep ocean mining operation may be conducted in two distinct phases. These phases, in this model, are referred to as prospecting and exploration. The prospecting phase consists of a program of resource assessment in a large area of the ocean. In particular, for the model it is assumed that the prospecting operation examines a region approximately 14° of longitude by 8° of latitude. This is about one quarter of the nodule rich province that is bounded by the Clarion and Clipperton Fracture Zones, and considered to be the area that will be first brought to commercial production.[1] The object of the prospecting phase is to identify regions of the seabed that are particularly suited for ocean mining,[2] and this may be accomplished through an organized examination of the seabed comprising the collection of samples from the seabed and bottom photography in the region of the bottom samples.[3]

The second phase of the minesite identification and selection program, the exploration phase, uses the data compiled in the prospecting phase to select an area for the mining operations.[4] The area proposed for the minesite is then mapped. Soil and nodule samples are taken in order to determine the optimum mining procedures to be used during the recovery phase of the mining operation.

The prospecting phase of the ocean mining operation must be conducted concurrently with the research and development program in order to provide information about the chemical characteristics of the nodules and the physical characteristics of the minesite for the designers of the processing and mining sectors of the ocean mining project. The exploration phase must follow the prospecting phase, and it must be begun prior to the initiation of recovery operations. The intensity of the exploration program may be such that the program could be completed prior to recovery operations, or it may continue during the recovery operations in order to delay expenditures to a later date in the project. In this model, the exploration program begins at the same time as the construction of the capital equipment, and the exploration is completed in two years.

The prospecting phase of the minesite identification program is described in part II of this appendix. The exploration program is described in part III. The initial values of the variables used in the description of the prospecting and exploration programs are summarized in part IV.

II. Prospecting Phase

The purpose of the prospecting phase is to provide sufficient information to identify potential minesites. The information is used to estimate the distribution of assays, boundaries, and continuity of the deposit.[5] Topographical and environmental data are also required in order to make initial evaluations of the technical feasibility of mining operations in the area.[6] This data would normally be gathered in a series of prospecting cruises which collect data from specified points in the region under investigation. The data would include nodule samples to be assayed and photographs of the seabed surrounding the site of the sample.[7] Measurements of the topography of the sea floor would be made by acoustic methods from the research vessel.[8]

A possible prospecting operation has been proposed by Metallgesellshaft AG.[9] The sampling pattern for this operation is shown in Figure A-1. The operation is conducted in three stages. The first stage is an examination of a region measuring 840 miles by 480 miles (approximately 14° by 8°). The region is sampled at 40 points, and the information from these samples the research work

A Coarse-grid prospecting:
Discovery of nodule deposits and determining their extension;

B Close-grid prospecting:
Delimitation of nodule resources of economic interest;

C Detailed exploration
Detailed investigation of the delimited nodule resource the results serving to evaluate the deposit

D Profils with locations

E Population
5–10 kg/m²

F Population
10–15 kg/m²

G Population
>15 kg/m²

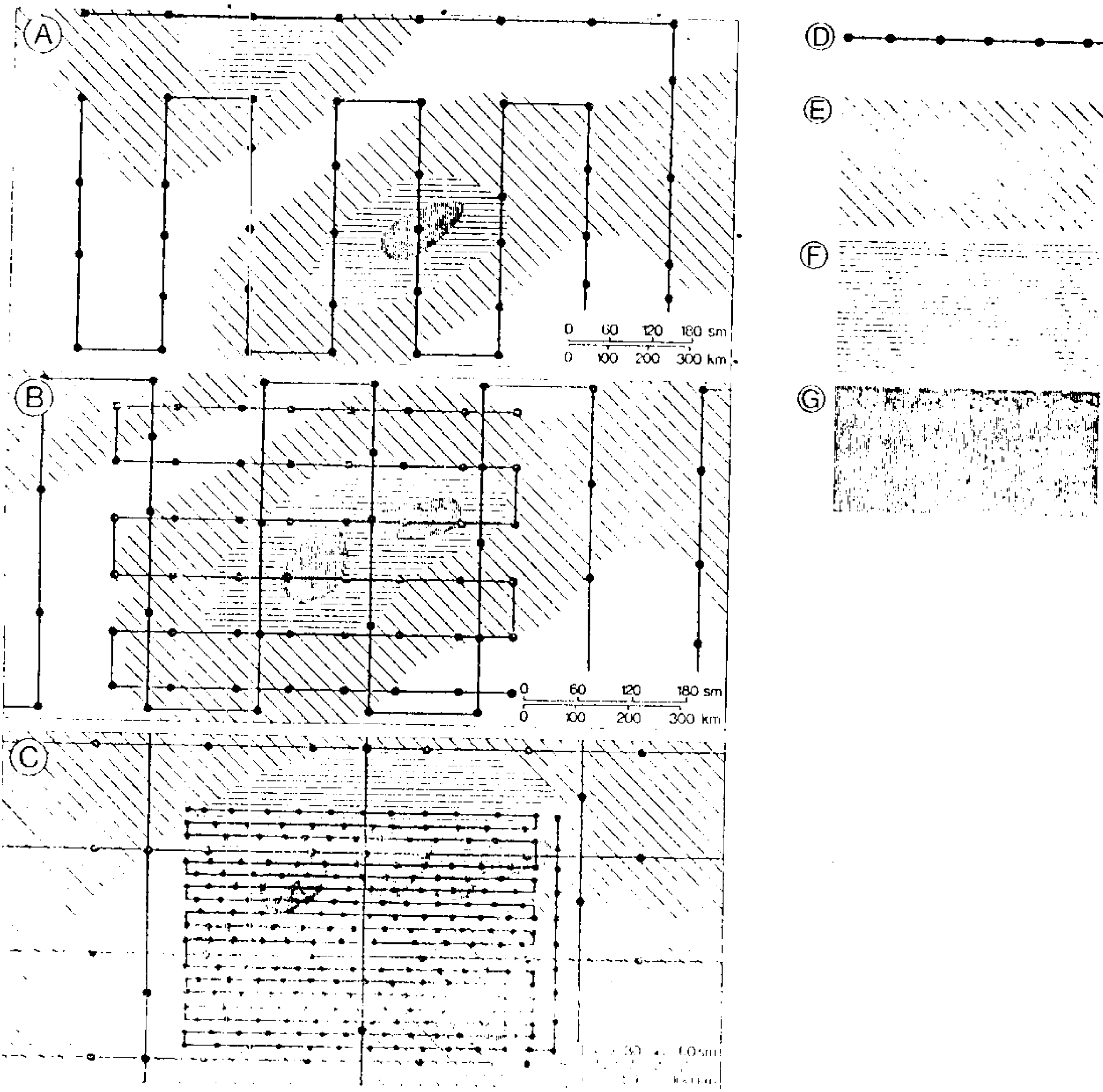


Figure A-1. Phases of the Prospecting Work[10] is used to narrow the area to be examined in the second stage. This stage covers a region measuring 420 miles by 300 miles, and it is sampled at 48 points. The results of this stage are used to specify the region to be examined in the third stage, which is a detailed examination of an area approximately 210 miles by 130 miles. The third stage includes 235 sample points.

The costs of the prospecting phase consist of the costs of the operation of the research vessel and of the cost of the scientific research party that analyzes the data. Operating expenses of ocean going survey ships run approximately $5000 per day.[11] In this model it is assumed that collection of a bottom sample by a dredge and photographs by a camera lowered to the seabed take about three hours at each sample point. Since the sample points on the first stage of the prospecting phase are separated by over one hundred miles (more than ten hours sailing time at ten knots), it is assumed that only one sample is taken per day during the first stage of prospecting. Thus, with a six day work week the sampling operation will take 6.5 weeks. The round trip travel time to the prime nodule region from a base in Hawaii is ten days so the total sea time is eight weeks. At a weekly operating cost of $35,000 the cost of the coarse survey is $280,000. The points on the close grid are separated by only 60 miles and it is possible to make two dredge hauls per day, so the 48 points may be sampled in four weeks. Travel time increases the total time to 5.5 weeks with a cost of $192,500. The detailed grid may be sampled at three sites per working day so the grid may be completed in 13 weeks of sea time. Survey cruises are limited to about one month so three round trips to the survey site are required.[12] Total sea time is 17.5 weeks at a cost of $612,500. The total cost of the three sea operations of the prospecting phase is $1,085,000.

Prospecting costs must also include the costs of the research and analysis team that oversees the operation and interprets the data. The composition of such a team is shown in Table 1. The annual cost of the team is $328,000.[13] Assuming two months of preparation and two months of analysis for each survey cruise brings the total time requirements for the prospecting operation to 19 months. The cost of the analysis team for this period is $519,000. The total cost of the 19 month prospecting operation comes to $1.6 million.

Table A-1, Composition of the Research and Analysis Team

Position	Salary	Benefits	Total
Senior Marine Geologist	30K	15K	45K
Staff Geologist	20K	10K	30K
Technician	12K	6K	18K
Technician	10K	5K	15K
Programmer	15K	7.5K	22.5K
Administrative Assistant	12K	6K	18K
Secretary	10K	5K	15K
Sub-total	109K	55K	164K
Overhead (100% of labor cost)			164K
TOTAL ANNUAL COST			328K

III. Exploration Phase

There are two objectives of the exploration phase. One is to conduct a survey of the potential minesites identified in the prospecting phase and to acquire samples of nodules and of the seabed at many points in that region. The goals of the survey study are:

1) to determine nodule ore deposits giving boundaries, shape and size of deposits;
2) to determine nodule populations and concentration; and,
3) to acquire soil mechanics data.[14]

The second objective is to obtain a topographic map of the area to be used in the determination of tracks for the mining vessel to follow during recovery operations.[15]

The first step in determining the cost of the exploration phase of the deep ocean mining project is to estimate the size of the minesite that will be needed to provide ore for the entire life of the mining operation. In this model the size of the site, or claim size, is identified by the variable (CLMSZ). It is expressed as a function of:

1) the lifetime of the project expressed in years (KOPS);
2) the annual production rate of dry ore (ARO), described above;
3) the surface abundance of nodules on the ocean floor, expressed in pounds/square foot (ABB);
4) the sweep efficiency, which represents the fraction of the minesite actually passed over by the harvesting system (SWPEFF);
5) the efficiency of the collector which states the fraction of the nodules in the swept area which actually get picked up (COLEFF);
6) the water-nodule separation efficiency (WNSEF), described above; and,
7) the area of the minesite actually available for mining (AAFM), which excludes areas of low-grade deposits or unfavorable topography. Thus the size of the minesite may be expressed:

$$\text{CLMSZ} = \frac{\text{KOPS x ARO}}{\text{ABB x SWPEFF x COLEFF x WNSEF x AAFM x 5380}}$$

(The conversion factor 5380 changes the units of surface abundance (lb/ft^2) to units of $tons/km^2$).[16]

For the baseline case (an operation with a 25 year production life and a production rate of three million tons per year) the claim size is approximately 27,000 km^2.

The cost of conducting survey and mapping cruises is proportional to the area to be explored. The total cost of the cruises can be calculated from the area of the claim (as determined above) and the cost of the exploration cruises when calculated in cost per unit area. These costs are discussed in the following paragraphs and are included in the calculation of total exploration cost.

Nodule and soil samples may, for example, be obtained from a grid with a point separation of 2 kilometers at a rate of 20 samples per day by the use of a sampling device that falls to the seabed, plunges into the soil, releases its ballast and returns to the surface with the sample. A six day work week would result in a survey rate of 480 km^2 per week at a weekly cost of $35,000. Since the survey cruises are limited to 30 days on station and ten days are spent in round trip from port to the site and back, the cost efficiency of the survey is reduced by 25%.[17] The cost of the soil survey is $97 per km^2.

A map of the mining region may be obtained by the use of an integrated instrument system consisting of a precision depth recorder, a television camera, and a side scan sonar. The depth recorder is mounted on the research vessel to record the terrain of the site. The television camera is towed near the sea floor so the size and distribution of the nodules can be seen. The sonar is towed farther from the sea floor so it can produce a record of the terrain 100 meters to each side of the vessel's path. If there is 50 meters of overlap between successive passes of the research ship and the ship travels at 5 km/hour, then the ship will survey 108 km^2 per week. The survey costs, including travel time to and from the minesite for each month on station, come to $432 per km^2.

The cost of the exploration program is comprised of the costs for the research vessels used in the soil sampling and mapping surveys described above and for the accompanying research team. The vessel costs of each type of survey are expressed in terms of dollars per unit area of the site. The costs of the surveys are based on a rental rate for the research vessel (SHRENT) of $5,000/day.[18] The annual cost of the research team is considered to be independent of the size of the minesite and is assigned a value of $330,000 per year, as shown in Table A-1.

The costs of the mapping survey (MAPCST) and the soil survey (SOILCS) are adjusted by the daily charter rate of the research vessel (SHRENT) and multiplied by the area that is to be explored (CLMSZ) to obtain the total cost of the operations conducted at sea. The cost of the research and analysis team that examines the exploration data is determined from the annual cost of the research staff (EXPLBR) and the length of the exploration period (KPE). The total cost of the exploration program (EXPCST) is the sum of the cost of the operations conducted at sea and the cost of the research and analysis team:

$$EXPCST = EXPLBR \times KPE + CLMSZ \times (MAPCST + SOILCS) \times SHRENT/5000$$

In this equation the ratio (SHRENT/5000) is used to allow the cost of the mapping and soil sampling operations to vary with changes in the research vessel rental rate.

IV. Initial Conditions

The initial values of variables used to compute the costs of the prospecting and exploration programs are tabulated on Table A-2, and are also found in Chapter IV of the text.

TABLE A-2

Initial Values of Input Variables in the Prospecting and Exploration Section

Variable	Description	Value	Units
AAFM	Area of Site Available for Mining	.8	
ABB	Surface Abundance of Nodules on Seafloor	2	lb/ft^2
ARO	Annual Rate of Recovery of Ore	3000000	Dry Short Tons
COLEFF	Collector Efficiency	.65	
EXPLBR	Cost of Labor in Exploration Program	660000	Dollars
KOPS	Nodule Recovery Lifetime	25	Years
MAPCST	Cost of Continuous Mapping Survey	432	$\$/km^2$
PROSCS	Cost of Complete Prospecting Program	1600000	Dollars
SHRENT	Daily Rental Rate of Research Vessel	5000	$/Day
SOILCS	Cost of Discrete Soil Sampling Survey	97	$\$/km^2$
SWPEFF	Sweep Efficiency	.50	
WNSEF	Water-Nodule Separation Efficiency	1.0	

Appendix A Notes

1. D. R. Horn, _et al._, _Ocean Manganese Nodules - Metal Values and Mining Sites_, unpublished manuscript, Columbia University, 1973, p. 10.

2. J. E. Flipse, _et al._, "Pre-Production Manganese Nodules Mining Activities and Requirements," in _Mineral Resources of the Deep Seabed 1973_, United States Senate Committee on Interior and Insular Affairs, Sub-Committee on Minerals, Materials, and Fuels, p. 607.

3. Ibid., pp. 609-610.

4. Walter Kollwentz, "Prospecting and Exploration of Manganese Nodule Occurrences," in _Metallgesellschaft AG - Review of the Activities_, Edition 18, p. 18.

5. Flipse, _et al._, p. 610.

6. _Ibid._

7. _Ibid._, p. 612.

8. _Ibid._

9. Kollwentz, pp. 18-19.

10. _Ibid._, p. 19.

11. Flipse, _et al_, p. 623.

12. _Ibid._, p. 618.

13. _Ibid._, p. 614. Costs for the scientific staff in 1973 are cited to be between $150,000 and $300,000 per year.

14. _Ibid._, p. 616.

15. _Ibid._

16. _Ibid._ Our equation for claim size is similar to one proposed in Flipse, _et al_. The reader should note, however, that the surface abundance in our model is measured in dry pounds per square foot, while Flipse uses wet pounds per square foot.

17. J.E. Flipse _et al_, "Preproduction Manganese Nodules Activities and Requirements," in Mineral Resources of the Deep Seabed, 1973, U.S. Senate Committee on Interior and Insular Affairs, Sub-Committee on Minerals, Materials, and Fuels, p. 12.

18. _Supra_ note 11.

APPENDIX B, COST ESTIMATION OF THE MINING SECTOR

I. Introduction

The mining system used in this model is a hydraulic lift system which is based on and controlled from a floating platform that cruises the sea above the minesite. The system is divided into five sub-sectors: mining platform, power plant, pipe handling system, lift system, and the navigation and control system. Although it is not the most expensive of the sub-sectors, the lift system is the central part of the design. A poorly designed lift system can require too much power for economic operation, causing the entire mining and processing operation to appear financially unattractive. Because of its effect on the overall economics of the nodule mining project the operation and design of the lift is examined in detail as part of the mining sector of the program. The analysis of the lift system provides the dimensions of the lift system, as well as the power requirements of the lift pump and of the ship's propulsion system. This information is then used in the determination of the cost of the ship's power plant and the annual operating costs of fuel and materials of the mining sector. The costs of the mine ship and of the pipe handling system are determined from the annual production rate of ore and are based on cost estimates for equipment used in oil drilling applications and from the costs of prototype equipment for ocean mining operations.

This appendix is designed to serve two purposes: to explain the operation of the lift analysis section and the theory it is based on, and to explain the operation of the mining section of the program. To aid in this explanation flowcharts of the model are provided, and the individual equations are described in the text. The variable names used in this appendix are the same as appear in the program. The values of the input variables used in the mining sector analysis are summarized in Table B-1 which appears after the text of this appendix as well as in Chapter IV of the text. After the input variable summary, equipment specification sheets are provided that describe the characteristics of the equipment that is examined in the capital cost estimation section of the mining sector model.

II. Lift System Analysis

The commercial mining companies have developed the slurry transport method as the recovery system upon which they are relying.[1] In this system, the nodules are separated from the sediment of the seabed and are fed into a pipeline that reaches up to the surface and the mine ship. The nodules are mixed with water to form a slurry which is pumped through the pipeline to the surface. The nodules tend to fall downward through the water but since the water velocity in the pipe relative to the surface of the ocean is greater than the terminal velocity of the nodules, there is a net movement of the nodules to the surface. At the surface the nodules are separated from the discharge of the pumping system and are sent to the shore for processing. The water discharge of the lift system, which contains sediment from the seabed and fine grains of the nodules that are broken during the lift process, may be discharged directly into the surface waters of the ocean, treated to remove the particles and then discharged into the surface waters, or discharged below the surface to reduce the effects on the ocean environment.

Two different systems of powering the lift have been proposed: conventional slurry pump and air-lift system. The conventional slurry pump utilizes a submerged pump that pushes the slurry to the surface. Since the pump cannot draw a suction greater than the vapor pressure of water the peak pressure that the pump can generate is limited by the depth at which the pump is located.

An alternative to this system is the air-lift system, in which the major items of equipment are all maintained on board the mineship. This system operates by injecting air into the water of the lift pipe at several points between the seabed and the surface. The mixture of air and water is less dense than the ocean water outside of the pipe so it is forced upwards to the surface. As water rushes into an opening at the bottom of the pipe, nodules are mixed into the flow and the resulting slurry is lifted to the surface. The air-lift system has been tested by Deepsea Ventures in the Atlantic Ocean on the Blake Plateau in 3000 feet of water.[2] Deepsea Ventures is currently testing the air-lift system in the Pacific Ocean to determine its performance at greater depths.[3]

In spite of the limitations of the conventional pumping methods, this system is used in this study because it can be modeled using conventional slurry transport systems as a source of information and because the design calculations are based on available information in fluid mechanics. The air-lift system, with its complex mixture of solid, liquid, and gas, requires extensive testing before the operational characteristics of the system can be determined.

The hydraulic lift system used in the model is described by a number of variables, including the water depth at the mine site, the depth at which the lift pump is submerged, and the size of the nodules. Two variables, the inside diameter of the lift pipe and the fraction of the total volume of the slurry occupied by nodules, are particularly important because they are selected to minimize the power consumption of the lift. The model examines lift systems that use a wide range of pipe diameter and solid fraction and selects the design that results in the lowest power requirement of the combined lift and propulsion systems. These results are then used in determining the capital and operating costs of the mining system. The operation of the computer analysis of the lift system and of the mining sector is described below. Also, the analysis of the lift system section of the program is summarized in the flowchart provided in Figure B-1.

The principle of the hydraulic lift is to move the water in the lift to the surface faster than the nodules can fall back through it to the seafloor. The analysis of this system requires the identification and specification of three velocities: that of the nodules relative to the water in the pipe, that of the nodules relative to the ocean surface, and that of the water in the lift relative to the ocean surface. The velocity of the nodules relative to the water in the pipe is the terminal velocity of the nodules, VT, and may be estimated from the equation for the terminal velocity of a sphere in water.

For this model the terminal velocity of a nodule is estimated by assuming that the nodule is a sphere and by using experimental results that relate drag forces on a sphere to its velocity. When the nodule is at its terminal velocity, the drag force on the nodule is equal to the weight of the nodule when it is completely submerged. The experimental results relate the drag force and dimensions of the nodule to an experimental value known as the drag coefficient. The drag coefficient is expressed as:

$$C_D = \frac{\text{Drag}}{\text{Rho}_w \times V \times V \; A/2}$$

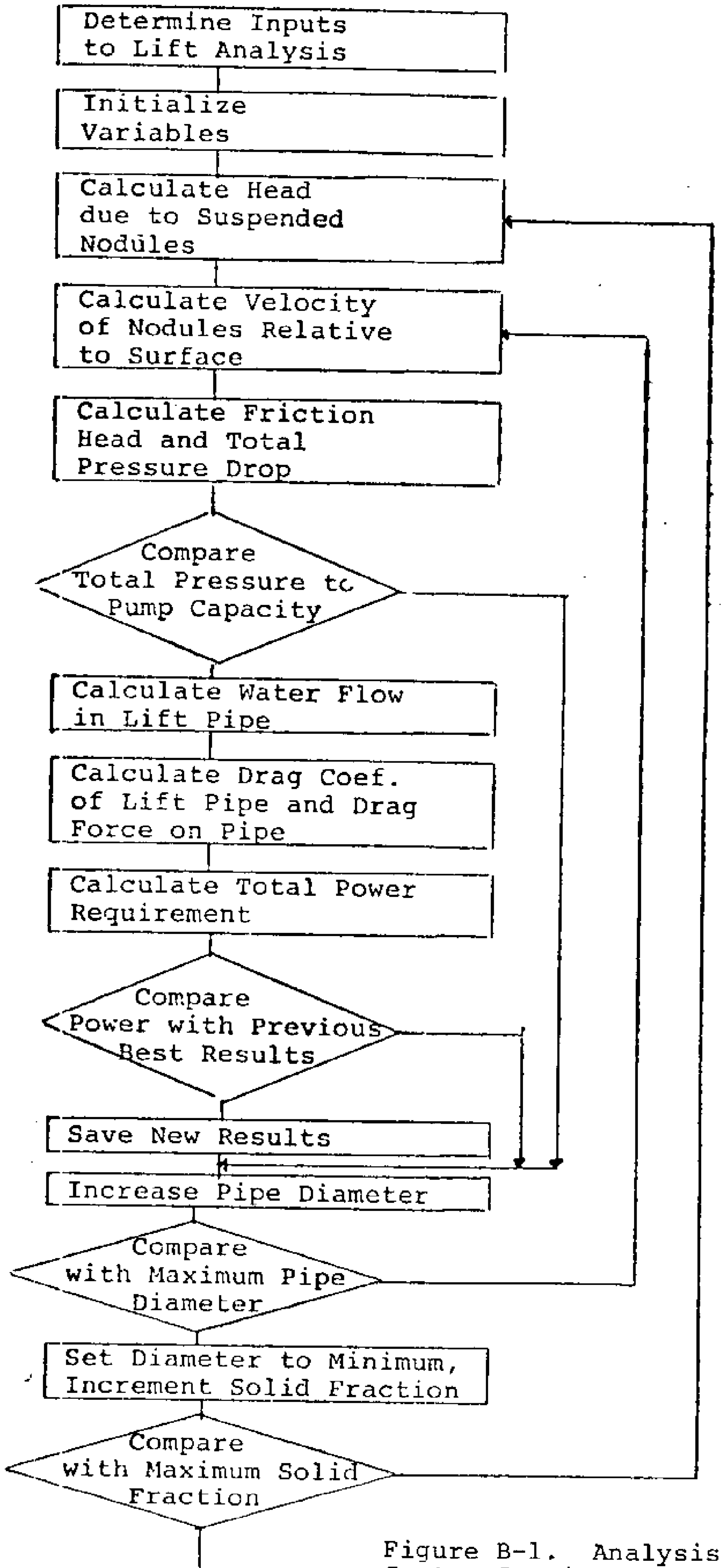


Figure B-1. Analysis of Lift System Section where Rho_w is the density of water in pounds-mass per cubic foot, V is the velocity of the sphere relative to the surrounding water (in feet per second), and A is the frontal area of the sphere in square feet.[4] When the sphere is at terminal velocity the drag force is equal to the submerged weight of the sphere which is given as:

$$Drag = (Rho_n - Rho_w) \times G \times Volume$$

The density of the nodule is expressed in pounds-mass per cubic foot. The acceleration of gravity, G, is given as 32.2 feet per second per second. After expressing the volume and area as functions of the nodule diameter, Dn, the drag coefficient may be written as:

$$C_D = [Rho_n/Rho_w - 1] \times 4/3 \times G \times D_n/V^2$$

and the terminal velocity may be expressed as:

$$V_t = SQ.RT.\ [(Rho_n/Rho_w - 1) \times 4/3 \times G \times D_n/C_D].$$

The forward velocity of the mineship (VF) is calculated from the annual rate of dry ore (ARO), the number of mineships in operation (NMSH), the length of the work year and the work day at sea (WYS and WDS), the collector width and pickup efficiency (COLWTH and COLEFF), the abundance of nodules on the surface of the seabed (ABB), and the fraction of the nodules lifted to the surface that are recovered from the lift discharge (WNSEF). The velocity is calculated in two equations. The first is the annual rate of ore recovered per mineship (AROHPS):

$$AROHPS = ARO/(WNSEF \times NMSH).$$

The second is the forward velocity of the mineship (VF):

$$VF = AROHPS/[(1.8 \times WYS \times WDS) \times ABB \times COLWTH \times COLEFF].$$

The third input to the lift system analysis section is the hourly rate of wet ore recovered per mineship (HRWOHS):

$$HRWOHS = 1.35 \times ARO/(WNSEF \times WYS \times WDS\ NMSH).$$

The number 1.35 accounts for the weight of water retained in the internal pores of the nodules after the nodules are drip dried.[5]

The second step of the lift system analysis is to set the variables to their initial conditions. The solid fraction (SF) is set to a value of 0.2%; the pipe diameter (D) is set to .4 feet; and the minimum power consumption of the lift and propulsion systems is set at 10 million horsepower.

After the input variables have been calculated and the values of diameter, solid fraction, and power consumption have been set to their inital values the analysis begins the computation of the combined power consumption of the hydraulic lift and the ship's propulsion system.

In our model the power consumption of the hydraulic lift is expressed as the total pressure head (in feet of water) in the pipe times the flow rate of the slurry. The total head is composed of the head due to the increased density of the water-nodule mixture and the head due to friction with the pipe wall.

The head due to the increased density of the slurry relative to the density of the surrounding ocean water is given as a function of the density of the nodules and of the water, and the solid fraction of the slurry volume (SF):

$$PS = \frac{(RHOW - PHOW)}{RHOW} \times SF \times DW.$$

Friction losses in the lift pipe are a function of the water velocity in the pipe. The water velocity in the pipe (VW) is the sum of the velocity of nodules relative to the surface (VR) and the velocity of nodules relative to the surrounding water, which is the terminal velocity that is described above. The velocity of the nodules relative to the ocean surface is a function of the required rate of mass transport, the cross-sectional area of the lift pipe, and the fraction of the lift pipe volume that is filled with nodules. This velocity can be expressed also as a function of the volume rate of flow of nodules that is required. The volume rate of flow of nodules is given as the rate that would occur if the entire volume of the pipe moved at a velocity VR times the fraction of the pipe actually occupied by solids, SF. Thus, the volume rate of flow of nodules is the velocity of the nodules (VR) times the area of the pipe times fraction of the pipe occupied by solids.

$$\text{Vol Flow Rate}_n = VR \times PI \times D^2/4 \times SF$$

The volume flow rate can be expressed in terms of the harvesting rate of nodules, where the mass flow rate (HRWOHS) is in short tons of wet nodules per hour and the density is in pounds per cubic foot.

$$\text{Vol Flow Rate}_n = (HRWOHS/3600) \times (2000/Rho_n).$$

The two rates are equal, so the velocity of the nodules relative to the ocean surface can be expressed in feet per second as:

$$VR = \frac{HRWOHS/3600 \times 2000/Rho_n}{PI \times D^2 \times SF/4}$$

The velocity of the water in the pump system is the difference between the velocity of the nodules relative to the surface and the velocity of the nodules relative to the surrounding water. Since these velocities are in opposite directions the water velocity relative to the ocean surface is the sum of the magnitudes of the velocity of the nodules relative to the surface and the velocity of the water relative to the nodules.

Next, the head due to pipe friction is computed as a function of the Darcy friction factor (FF) which is defined as:[6]

$$FF = \frac{PF}{DW \times VW \times VW/(2 \times G \times D)}$$

where G is the acceleration of gravity (32.2 feet/second^2) and PF is the friction head, measured in feet of water. The value of FF for commercial steel pipe is estimated to be .013.[7] The value of the friction head is determined as:

$$PF = FF \times DW \times VW^2/(2 \times G \times D).$$

The total pressure head (TPR) is the sum of the head loss due to pipe friction (PF) and the head due to the increased density of the slurry relative to the density of water (PS):

$$TPR = PF + PS.$$

The pressure requirement of the system is calculated for each combination of diameter and solid fraction. If the pressure drop for a particular combination is greater than the capacity of the pump then that combination is not allowed and the parameters are changed to the next step. If the pressure loss is within the capacity of the pump then the power consumption of the lift is determined.

The slurry flow rate of the lift is equal to the sum of the flow rate of water and the flow rate of nodules:

$$Q = (PI \times D^2/4) \times [(1 - SF) \times VW + SF \times VR].$$

The theoretical power consumption of the pump (PPOW) is calculated as:

$$PPOW = TPR \times Q \times RHOW \times (G/32.2)/550$$

where G is the acceleration of gravity in feet per second per second, 32.2 is used in the conversion of pounds mass to pounds force, and 550 is the conversion factor for changing foot pounds per second into horsepower. Since the value of G is 32.2 this equation can be reduced to:

$$PPOW = TPR \times Q \times RHOW \times 550.$$

The ideal power requirement of the ship propulsion system is computed from the drag of the pipe (DRAG) and the forward velocity of the pipe (VF):

$$SPOW = DRAG \times VF/550.$$

The number 550 is a conversion factor to give SPOW in horsepower while the drag is given in pounds-force and the velocity in feet/second. The drag of the pipe is computed for a pipe with a wall thickness of 1/2 inch and a length equal to the water depth. The calculation of the drag includes the drag coefficient of a cylinder and the density of water.

$$DRAG = CD \times RHOW \times VF^2 \times (D + .08) \times DW/(2 \times 32.2)$$

The drag is given in units of pounds-force which are obtained by the relation:

$$1\ lb_m = \frac{1\ \text{pound-force}}{32.2\ ft/sec^2}$$

The drag coefficient is a variable that is determined by experiment to be a function of the diameter of the pipe and the forward velocity. The model uses three different formulations of the drag coefficient to cover the range of diameters and velocities used in this model. The selection of the particular formulation is made by the value of the Reynold's number, a non-dimensional number that represents the relative effect of frictional and inertial forces in a fluid system. The value of the Reynold's number in the model is determined for water (kinematic viscosity of 0.000015 ft^2/sec) as:[8]

$$RENO = VF \times D/(1.5 \times 10^{-5})$$

The drag coefficient (CD) is given as:

1) $CD = .13 \times (VF \times D)^{.41}$, if RENO is greater than or equal to 500,000;
2) $CD = 6.7 \times (VF \times D)^{-1.53}$, if RENO is less than 500,000 but greater than 200,000; and
3) CD = 1.25 if RENO is less than 200,000.

The curve that results from these three estimates is shown in Figure B-2.[9]

The power requirement of the ship system is determined from the work done by the pump of the hydraulic lift and the power consumed by the ship in moving the pipe forward through the water. Neither power system is perfectly efficient so the actual power consumption is greater than the theoretical power requirement. The total power consumption, PWR, is expressed in horsepower as:

$$PWR = PPOW/PEF + SPOW/SEF$$

where PPOW is the ideal power requirement of the lift pump, PEF is the efficiency of the pump, SPOW is the ideal power consumption of the ship propulsion system in towing the pipe at velocity VF, and SEF is the efficiency of the propulsion system.

At this point in the analysis the computed value of power consumption (PWR) is compared to the lowest value of power consumption previously calculated (MINPOW). If the value of PWR is less than MINPOW then the values of pipe diameter, solid fraction, pump power consumption, ship power consumption, and total power requirement are saved:

DM = D,
SM = SF,
PPOWM = PPOW,
SPOWM = SPOW, and
MINPOW = PWR.

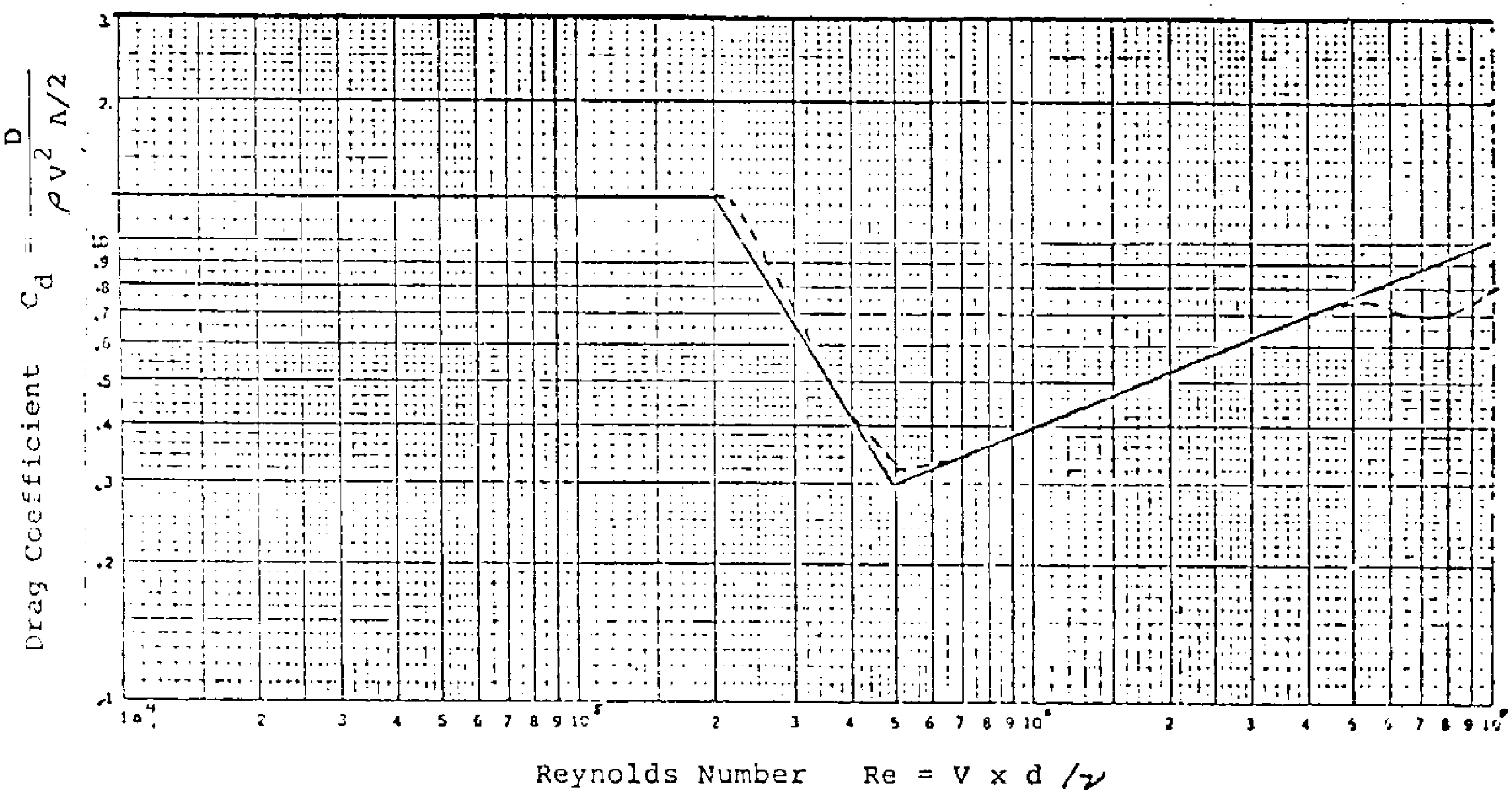


Figure B-2

Drag coefficient of a cylinder as a function of Reynolds number. The solid line represents the approximation used in the model. The experimental value of the drag coefficient, where it differs from the approximation, is shown by the dashed line. (Experimental results from R.H. Sabersky and A.J. Acosta, Fluid Flow - A First Course in Fluid Mechnaics, (New York, 1967), p. 163.)

If the value of PWR was greater than or equal to MINPOW, then the values of D, SF, PPOW, SPOW, and PWR are not saved.

At this point the model has analyzed the lift system for a specific value of diameter and solid fraction. Next, the value of D is increased by an increment of 0.1 feet and the program returns to the calculation of the relative velocity of the nodules (VR) and begins a new analysis. When D has been increased to its upper limit of 4.5 feet the diameter is assigned its original value of 0.4 feet and the value of the solid fraction is increased. If the solid fraction is less than .02 then the value is increased by 0.002. When the solid fraction has been increased to 0.2 then the increment becomes 0.1. When the value of solid fraction reaches .20 the analysis is complete and the program continues to the calculation of capital and operating costs of the mining sector.

III. Mining Sector Capital Cost

The capital cost of the mining sector is calculated for each of five sub-sectors: mining platform, pipe handling equipment, power plant, lift system, and navigation system. The characteristics of each sub-sector are described in the specification sheets that follow this appendix.

The cost of the mining platform (SHPCST) is calculated from a power law equation:

$$SHPCST = BASMSH \times (HRWOHS)^{EXPMSH}$$

The values of BASMSH and EXPMSH are selected to estimate the cost of a mineship that recovers ore at a rate between one and four million dry short tons per year.

The pipe handling equipment that is installed on the mining vessel is developed to assemble the hydraulic lift system and to suspend the system from a roll, pitch, and heave compensated platform in order to reduce the stresses that might be imposed by the movement of the mineship. This sub-sector is a large component of the mining sector capital cost, exceeded only by the cost of the mineship itself. The cost of the pipe handling equipment is estimated by a power law relationship that extrapolates the cost of full size equipment from the published cost of prototype equipment that is being tested in the Pacific:

$$PHCST = 3{,}400{,}000 \times (HRWOHS/27.8)^{.6}$$

The cost of the power plant is based on a cost of $400 per horsepower for a plant that provides power for the operation of the lift system and for ship propulsion, but not for general ship service power which is included in the cost of the mining platform:

$$PWRCST = 400 \times MINPOW$$

The lift system is composed of the bottom units that collect nodules and separate them from the sediment, and of the hydraulic system. The hydraulic system is composed of a pipe string that reaches to the seabed, couplings that join the thirty foot lengths of pipe together, and a pumping unit which actually moves the slurry upwards to the surface.

The cost of the pipe string (PIPCST) is determined from the weight of the pipe (PIPWT), which is calculated for a pipe with an internal diameter of DM, a wall thickness of PIPTH, and a length equal to the depth of the water (DW). The density of the pipe material is specified by the variable DENS, which is set equal to the density of steel. The cost of the pipe is estimated by multiplying the weight of the pipe string by the cost of fabricated steel pipe (STCST). Thus, the cost of the pipe in the hydraulic system is calculated by two equations:

$$PIPWT = [(DM + PIPTH)^2 - DM] \times PI \times DW \times DENS/4.0$$
$$PIPCST = PIPWT \times STCST$$

The pipe used in the pipe string is fabricated in 30 foot lengths. Each length of pipe is joined to the next by a steel coupling. The cost of an individual coupling is specified by the variable CPLPR. The cost of all couplings used in the pipe string is given as:

$$CPLCST = (DW/30.) \times CPLPR.$$

The cost of the pump for the lift system is estimated from the power requirement determined in the optimization section (PPOWM):

$$PMPCST = 2771 \times PPOWM^{.41}$$

The cost of the motor for the system is also based on the pump power requirement, but it includes a variable that represents the efficiency of the pump (PEF). The cost of the motor is expressed as:

$$CSTMTR = 37.5 \times (PPOWM/PEF)^{.85}$$

The cost of the housing for the motor and pump is given a cost that is invariant:

$$HSGCST = 100{,}000.$$

The assembly of the pump, motor, and housing into a single pumping unit increases the cost of the unit to several times the cost of the individual items. This installation cost is accounted for by an installation factor (FACINS). The capital cost of the hydraulic system is the sum of the costs of the pumping unit, the pipe, and the couplings:

$$HSCC = FACINS \times (HSGCST + CSTMTR + PMPCST) + PIPCST + CPLCST.$$

Although the replacement of lost bottom units is considered to be an annual expense, the initial purchase of one year's supply of units is included in the capital cost of the lift system. The number of bottom units lost per year by a single ship is given by the variable BUPY, and the cost of a single unit is given as SBUCST. The investment in bottom units for one mineship is given as:

BUCST = BUPY x SBUCST.

The cost of the lift system for a single mineship is the sum of the capital costs of the hydraulic system and the bottom units:

LFTCST = HSCC + BUCST.

The cost of the navigation and position control equipment required by a mineship is considered invariant:

NAVCST = 5,000,000.

IV. Mining Sector Operating Costs

The operating costs of the mining sector are composed of energy, labor, materials, maintenance, insurance, and administration expenses. The first of these expenses, the cost of energy, is the annual cost of producing power for the operation of the hydraulic lift and propulsion systems. This cost (POWCST) is calculated from the power requirement that is determined in the lift optimizing section (POWMIN), the length of the work day at sea (WDS) and the work year at sea (WYS), and the cost of power at sea (PPRICE) in units of dollars per horsepower-hour:

POWCST = POWMIN x PPRICE x WDS x WYS.

The cost of ship's labor is the annual cost of salaries and benefits for the ship's crew. The cost of labor (CSTL) is specified by the annual cost of labor (ASCSTL):

CSTL = ASCSTL.

The variable ASCSTL is included in the input variable list so that the program operator may change it from its baseline value.

The cost of materials includes the annual cost of replacement of bottom units, pipe, and couplings. The annual cost of bottom units is calculated in the capital cost section of the program. The cost of replacing the pipe and couplings is determined from the cost of a pipe string and its couplings, as determined in the capital cost section, and the lifetime of the pipe string (PILF). Thus, the pipe replacement cost (PRCST) is given as:

PRCST = (PIPCST + CPLCST)/PILF.

The annual cost of maintenance of the mining sector (TMCST) is the sum of the maintenance costs for the ship (SHMCST), the pumping unit (PMMCST), and the bottom units (BUMCST). The individual maintenance costs are estimated as fractions of the equipment capital costs:

SHMCST = SHMFAC x SHPCST,

PMMCST = PMMFAC x (PMPCST + CSTMTR),

BUMCST = BUMFAC x BUCST.

The total maintenance cost is given by:

TMCST = SHMCST + PMMCST + BUMCST.

The annual insurance charge is based on the capital cost of the mineship and an insurance rate of 5.5%:[10]

FXCST = .055 x SHPCST.

The annual administration cost is expressed as a fraction of all of the operating costs described above. The fraction is given by the variable ADMFEE, and the cost is expressed as:

$$ADMCST = ADMFEE \times (POWCST + PRCST + CSTL + TMCST + FXCST).$$

V. Summary of Cost Estimation Results

The lift system analysis section of the program provides information about the design and power requirements of a single mineship. This information is used to calculate the capital and operating costs of the same single mineship. If the mining sector is composed of two or more mineships, each handling a fraction of the total production of nodules, then the total costs are obtained by multiplying the components of capital and operating costs by the number of mineships (NMSH).

The results of the cost estimation analysis described above are used to supply cost information for the financial analysis section of the model. This information is stored with costs from the transportation and processing sectors in two arrays. The costs in the arrays are stored in five groups: energy, labor, materials, fixed, and miscellaneous. Since maintenance costs are not explicitly stated in this form these costs are divided into labor and materials components and added to those elements of the array. For this purpose it is assumed that the maintenance costs are composed of two thirds labor cost and one third materials. The elements of the cost arrays are expressed as:

$$CAPCST(3,1) = NMSH \times SHPCST/10^6$$
$$CAPCST(3,2) = NMSH \times PHCST\ /10^6$$
$$CAPCST(3,3) = NMSH \times PWRCST/10^6$$
$$CAPCST(3,4) = NMSH \times LFTCST/10^6$$
$$CAPCST(3,5) = NMSH \times NAVCST/10^6$$

$$OPCST(3,1) = NMSH \times (POWCST/10^6)$$

$$OPCST(3,2) = NMSH \times [(CSTL + .67 \times TMCST)/10^6]$$

$$OPCST(3,3) = NMSH \times [(PRCST + BUCST + .33 \times TMCST)/10^6]$$

$$OPCST(3,4) = NMSH \times (FXCST/10^6)$$

$$OPCST(3,5) = NMSH \times (ADMCST/10^6)$$

Table B-1, Initial Values of Input Variables in the Mining Sector

Variable	Description	Value	Units
ABB	Surface Abundance of Nodules[11]	2	lb/ft^2
ADMFEE	Administration Expense Fraction[12]	.064	
ARO	Annual Rate of Recovery of Ore	3000000	Dry Short Tons
ASCSTL	Annual Cost of Labor per Mineship	2100000	Dollars
BASMSH	Mineship Cost Equation Multiplier	4550000	Dollars
BUMFAC	Bottom Unit Maintenance Cost Fraction	.05	
BUPY	Number of Bottom Units Replaced per year per Ship	2	
CDS	Drag Coefficient of Nodule [13]	.5	
COLEFF	Collector Efficiency [14]	.65	
COLWTH	Collector Width [15]	30	Feet
CPLPR	Price of Single Pipe Coupling [16]	7700	Dollars
DENS	Density of Pipe Material	485	lb/ft^3
DN	Diameter of Nodule [17]	.125	Feet
DW	Depth of Water at Minesite [18]	18000	Feet
EXPMSH	Mineship Cost Equation Exponent	.39	
FACINS	Pumping Unit Installation Factor	3.4	
FF	Darcy Friction Factor[19]	.013	
NMSH	Number of Mineships in Mining Sector	1	
PEF	Pump Operating Efficiency [20]	.65	

Variable	Description	Value	Units
PILF	Pipe String Lifetime	1	Year
PIPTH	Wall Thickness of Lift Pipe	.04	Feet
PMMFAC	Pumping Unit Maintenance Cost Fraction	.05	
PMPDTH	Submergence Depth of Pumping Unit	3000	Feet
PPRICE	Price of Power at Sea	.03	$/HP-HR
RHON	Density of Nodules	128	lb/ft^3
RHOW	Density of Seawater	64	lb/ft^3
SBUCST	Cost of Single Bottom Unit	1500000	Dollars
SEF	Ship Propulsion System Efficiency	.65	
SHMFAC	Ship Maintenance Cost Fraction	.05	
STCST	Cost of Fabricated [21] Pipe	1	$/lb
WDS	Work Day at Sea	24	Hours
WNSEF	Fraction of Nodules Recovered from Lift	1	
WYS	Work Year at Sea	300	Days

SECTOR: Mining

SUB-SECTOR: Mining platform

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Mineship configured similar to conventional deepwater oil drilling vessels. Central moon pool is included, but pipe handling tower, power plant, navigation equipment, and lift system are considered separately. Temporary stowage for nodules is included with capacity for six days of nodules.

COST FORMULA: $4{,}550{,}000 \times (\text{hourly rate of wet ore harvested})^{.39}$

COST IN BASELINE MODEL: $53,770,000

REFERENCE: Ocean Industry, January, 1976.

SECTOR: Mining

SUB-SECTOR: Pipe handling system

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: System includes a roll, pitch, and heave compensated platform, a pipe suspension tower, and a pipe transfer system.

COST FORMULA: $\$3,400,000 \times (\text{hourly rate of wet ore per ship}/27.8)^{0.6}$

COST IN BASELINE MODEL: $20,660,000

REFERENCE: Mining Congress Journal, Feb. 1977, p. 140.

ALTERNATE REFERENCES: Ocean Industry, "Deepsea Miner II Completes first Phase of Sea Trials," April, 1977, pp. 75-76.

SECTOR: Mining

SUB-SECTOR: Power plant

MODULE: N/A

COMPONENT: N/A

DESCRIPTICN: Steam plant and turbines and generators to produce power for propulsion and operation of the hydraulic lift. The cost of the power plant is estimated at $400 per horsepower, and the cost of fuel at $.03 per horsepower-hour.

COST FORMULA: 400 x (power requirement of lift and propulsion)

COST IN BASELINE MODEL: $6,820,000

REFERENCE: Private Industry Source

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Hydraulic lift system composed of three sub-components: pipe string, pumping unit, and collecting unit. The diameter of the lift pipe and the ratio of solid volume to total volume in the pipe are selected by the model to give the minimum power requirement of the pump unit and the ship propulsion plant.

COST FORMULA: Pumping Unit Cost + Pipe String Cost + Collecting Units

COST IN BASELINE MODEL: $9,530,000

REFERENCE: See further descriptions of the equipment sub-groups: pumping unit; pipe string; and, collecting units.

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: Pumping unit

COMPONENT: N/A

DESCRIPTION: Complete pump system for the mineship, including pump, motor, and housing. Pump is 6-stage centrifugal unit constructed of stainless steel. Motor is electric, operating in the sealed environment provided by the steel housing. Control of the pumping motor is maintained on the mineship by observing the electrical characteristics of the unit as it operates. The cost of the assembled unit is determined by multiplying the component costs by the installation factor (equal to 3.4). This factor includes installation material and labor, as well as construction indirects and sub-contractor fees.

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: Pipe string

COMPONENT: N/A

DESCRIPTION: The pipe string is composed of sections of steel pipe 30 feet in length, which are connected by tool joints to reach from the mineship to the seabed.

COST FORMULA: Pipe cost + coupling cost

REFERENCE: See component descriptions for steel pipe and for couplings.

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: Pipe string

COMPONENT: Pipe

DESCRIPTION: High strength (yield stress approximately 100,000 psi) steel pipe. Pipe thickness may vary, with thicker sections being used at the surface, but an average thickness is assigned for use in the program.

COST FORMULA: Weight of pipe x price per pound

REFERENCE: Price per pound of steel is estimated at $1 This is based on HY-80 steel used in the WHOI Giant Piston Corer (ref.: Personal communication with James Broda, April, 1976)

ALTERNATE REFERENCES: Arthur D. Little draft report uses a price of $.50 per pound of steel.

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: Pipe string

COMPONENT: Couplings

DESCRIPTION: Pin-and box tool joints, with an outside diameter of approximately 29 inches and weighing about 2300 pounds.

COST FORMULA: (water depth/30 feet) x coupling price

COST IN BASELINE MODEL: $7,700 per coupling

REFERENCE: Technological and Economic Assessment of Manganese Nodule Mining and Processing, a draft report prepared by Arthur D. Little, Inc. for the U.S. Department of the Interior, page 18.

SECTOR: Mining

SUB-SECTOR: Lift system

MODULE: Bottom unit

COMPONENT: N/A

DESCRIPTION: Passive dredge for collecting nodules, with remote observation equipment. Observation equipment includes a television camera, a forward-looking sonar, and a side-scan sonar with two armored cables connecting with the mineship. Cost of a single unit is $1.5 million. Units are provided for a full year of operation.

COST FORMULA: BUCST = BUPY x SBUCST

COST IN BASELINE MODEL: $3,000,000

REFERENCE: Metallgesellschaft, Metals from the Sea, pp. 28-29.
Private Industry Source
Personal Communication with Ernest Vincent, Head of Engineering, Klein Associates, Salem, N.H.

SECTOR: Mining

SUB-SECTOR: Navigation and positioning control

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Satellite navigation equipment and dynamic positioning equipment to maintain the ship position and heading during mining operations.

COST FORMULA: $5,000,000

COST IN BASELINE MODEL: $5,000,000

REFERENCE: Private Industry Source

ALTERNATE REFERENCES: Ocean Industry, January, 1976: Costs between otherwise identical mineships differ by $5 million due to use of dynamic positioning equipment in place of moorings.

APPENDIX B Notes

1. Conrad G. Welling, "Next Step in Ocean Mining -- Large Scale Test", Mining Congress Journal, December 1976, p. 46.

2. John G. Lecourt and D. Williams, "Deep Ocean Mining -- A New Application for Oil Field and Marine Equipment", Proceedings, Offshore Technology Conference, 1972, Paper #1410.

3. Welling, p. 50.

4. Rolf H. Sabersky and Allan J. Acosta, Fluid Flow -- A First Course in Fluid Mechanics, New York, 1964, p. 163.

5. J. D. Agarwal, et al., Processing of Ocean Nodules -- A Technical and Economic Review, presented at the 104th Annual Meeting of AIME, p. 2.

6. Sabersky and Acosta, p. 163.

7. Ibid., p. 151.

8. Ibid., p. 383. This is the value of kinematic viscosity of fresh water at 40°F. It ranges from 100002 feet^2/second at 32°F to .00001 feet^2/second at 70°F.

9. Comments from industry sources suggest that these equations underestimate the value of the drag coefficient of the lift pipe. The model has been run for two cases with an increased drag coefficient. An increase of 100% results in an increase of 22% in total power consumption. When the drag coefficient is increased by a factor of 4, the power consumption rises to 84% above the baseline value to 31,000 horsepower.

10. The value of 5.5% reflects the operational safety record of new drill ships.

11. Horn et al., pp. 77-83.

12. E. G. Frankel and H. Marcus, Ocean Transportation, (Cambridge, 1973), pp. 328-378.

13. Acosta and Sabersky, p. 163.

14. Flipse et al., p. 656, suggests a range of .3 to .7 for collector efficiency. Industry sources report that test results show that the high efficiencies are attainable.

15. A. D. Little, Draft Report, p. 10.

16. *Ibid.*, p. 18.

17. Horn *et al.*, pp. 77083.

18. *Ibid.*

19. L. F. Moody, "Friction Factors for Pipe Flow", Trans. ASME, Vol. 66, No. 8, 1944, p. 671.

20. J. R. Backhurst and J. H. Harker, Process Plant Design, (New York, 1973), pp. 300-301.

21. Personal communication with James Broda, Woods Hole Oceanographic Institution.

APPENDIX C, TRANSPORT SECTOR

I. Introduction

The transportation sector is concerned with getting the nodules from the minesite to port. A rapid slurry transfer system is assumed for transferring the nodules from the mineship to the transport vessel and from the transport vessel to the port holding facility. The transport vessels are assumed to be modified ore carriers.

Section II of the appendix gives an explanation of that part of the computer program dealing with identifying a transportation system -- the System Determination section. The constraints and design parameters are given along with the logical sequence of the program. Most of the program steps, as they appear in the program, are also given.

Section III of Appendix C is the Cost Estimation section. In this section, capital and operating costs for the chosen transport system are given. The equations used to calculate the costs are shown as they appear in the program, along with an explanation of each equation. The first part of Section III deals with capital costs and the second part with operating costs.

Section IV is the Data Base section. In Section IV, all the data and information used to determine the costs curves are presented and referenced. In most cases, the actual derivations of the cost curves are shown. The graphs of the cost functions are included along with the actual data points used to calculate the analytic curves. All of the data is referenced to a list of sources at the end of the report.

Section V is comprised of two lists. The first is a list of the user defined variables, their code name, an explanation of their purpose, the initial value of each and the bounds on their validity. The second list is a compliation of all the variables used in the transportation sector including those internal to the program.

II. System Determination

The transport system is designed around the transport load it must handle. The system can accommodate up to four mineships, although they must all be of the same size.

The model will determine a combination of transport ships, the number and sizes, required to service each mining vessel. However, in cases where the mining ships are particularly large, a valve called LIMIT is used to constrain the size of the transport vessel. Since transport vessel size is related to mineship size, as the mineship size increases so does the transport size. This relation leads to the possibility of the transport size increasing so that it exceeds the draft restrictions of the port it is intending to use. It is for these reasons the variable LIMIT is introduced. It is used to set a size restriction on the transport so that it will be compatible with the intended port no matter what size mineship is assumed.

Table C-1

Sample Depths at Selected Ports[1]

S.W. = salt water
F.W. = fresh water

San Diego	40' - 34'	S.W.
Long Beach		
outer	60'	S.W.
inner	47'	S.W.
Los Angeles		
outer	51'	S.W.
inner	35'	S.W.
Columbia River		
entrance	48'	S.W.
Longview	35'	F.W.
Panama Canal	39'	S.W.

The slurry system used to transfer nodules to and from the transport ship is not determined within the model. It is assumed to be the same for any transport system used and is therefore given one base cost. The rationale and computations for determining the slurry system are given in the data base section of this appendix.

The previous paragraphs gave a brief description of what the system determination section does. The rest of this section on system determination follows the programming steps used in the transport sector. It explains the program logic and gives the program steps and equations beginning with the initialization sequence and going completely through the determination of the transport system.

All accumulating variables in the transport sector -- capital costs SCST1(I), SCST2(I) and operating costs STORES(I), SUBSIS(I), LABOR(I), MISC(I), LAYUP(I), INS(I), FUEL(I), and MANDR(I) -- are set initially at zero. Variables NUM(I) and MNSHP(I), ISIZE(I,1) and ISIZE(I,2) are also set initially to zero and ONE is set to 1.

```
      ONE = 1.0
      DO 213 I = 1, NMSH
      STORES(I) = 0.0
      SUBSIS(I) - 0.0
         .
         .
         .
      ETC.
  213 CONTINUE
```

The mineship sizes are set using the following loop:

```
      DO 2131 I - 1, NMSH
      2131 MNSHP (I) = BUFCAP
```

where BUFCAP is the maximum mineship size. The loop proceeds

NMSH times setting each mineship, MNSHP(I), as I goes from 1---NMSH, equal to the value of BUFCAP.

The system determination consists of three branches which are examined in series. The program uses the parameters Annual Rate of Ore Production (ARO), Work Days per Year (WYS), Speed (SPD), One Way Distance to Por t (OWDIS), BUFFER, and Number of Mineships (NMSH), and Maximum Mineship Capacity (BUFCAP).

From these inputs, the values of Daily Rate of Ore Production (DRWO), Rate of Wet Ore Production per Mineship (SRWO), Roundtrip Time (RDTRIP), and Time Between Arrivals (TBA) are obtained.

The total rate of wet ore mined per day is calculated as:

$$DRWO = 1.35 \times ARO/(1.12 \times WYS)$$

where 1.35 converts the dry ore to wet ore, and 1.12 converts short tons to long tons.

$$SRWO = DRWO/NMSH$$

$$RDTRIP = (2 \times OWDIS/(SPD \times 24) + BUFFER \times 1000 \; MNSHP(I)/(3500 \times 24)$$

$$TBA = BUFFER \times MNSHP(I) \times 1000/SRWO$$

Branch 1 -- The program first attempts to identify the system with the least number of the largest equal sized ships required to handle adequately the given load. A first approximation is given by:

$$ZNUM = RDTRIP/TBA,$$

where ZNUM is the number of ships of the size (BUFFER x MNSHP(I)) arriving at 'TBA' intervals required to service MNSHP(I). The value NUM(I) is the value of the next lowest integer from ZNUM. If NUM(I) is equal to 1, and there is only one mineship, the program will transfer to Branch 2 to determine a system that will incorporate two transports of smaller size. This is done to insure that complete shutdown will not occur if there is a transport failure.

Since the buffered capacity of the mineship is less than the actual capacity, that means that the mineship has a certain amount of storage capacity that is not being used. The program tries to use this capacity by reducing the number of transports required from ZNUM to NUM and making the size of the transports larger. For example:

Given a 60 thousand ton mineship, the buffered capacity would be 60000 x .8 = 48000 tons. If 2.25 ships of this size are needed to service the mineship, the program will attempt to find the two ships of 48000 plus tons that would be sufficient. If these two ships are below 60000 tons, the absolute maximum capacity of the mineship, they would be acceptable as possible choices and the buffered storage would be partially or fully utilized.

The calculations in Branch 1 proceed as follows:

SPLITS = 2 x OWDIS/NUM(I)

ISIZE(I,1) = IFIX[SRWO(I) x SPLITS/(SPD x 24 x .96 x 10000) + .5]

where SPLITS refers to the distance between ships and ISIZE(I,1) is the amount of ore mined during the time it takes for a ship to to go the distance SPLITS.

The program will then check to see if ISIZE(I,1) is less than or equal to LIMIT and less than or equal to MNSHP(I). If these constraints are not met, the program will jump to Branch 2. If the constraints are met, then the loop will be incremented by one and the next mineship-transport system will be determined.

Branch 2 - If system determination fails in Branch 1, then either the LIMIT constraint or the MNSHP constraint has been breeched. In this case, a new goal must be identified and new constraints applied. Since NUM(I) ships will not do the job, i.e. NUM(I) ships do not provide enough capacity to service the load, ZNUM will have to be used, where ZNUM is NUM(I) plus some fraction between 0 and 1. This means that ZNUM ships, the size of [BUFFER x MNSHP(I)] will be necessary. However, a sub-branch also exists here. If [BUFFER x MNSHP(I)] is greater than LIMIT, then the controlling condition will be that of LIMIT and ISIZE(I) will be equal to LIMIT. In a simplified flowchart form, Branch 2 appears as follows:

1. The system can be either MNSHP controlled or LIMIT controlled. The first assumption will be that of MNSHP controlled, i.e., the mineship is less than the LIMIT

2. Assume mineship controlled
   ISIZE(I,1) = IFIX[BUFFER x MNSHP(I)/
   (.96 + .5)

3. Check constraint
   If [MNSHP(I) x BUFFER .LT .LIMIT] go to 231

4. LIMIT constraints
   ISIZE(I,1) = LIMIT

5. Redefine TBA, ZNUM RDTRIP using LIMIT constraint
   TBA = LIMIT/[SRWO(I) x 1000]
   RDTRIP = (2 x OWDIS)/(SPD x 24) + LIMIT x
   1000/(35000 x 24)
   ZNUM = RDTRIP/TBA

6. Determine kicker
   ISIZE(I,2) = IFIX[ZNUM - NUM(I) x LIMIT/
   [(.95 x 1000) + .5]
   Go to 232

231 Determine ISIZE(I,2)
   ISIZE(I,2) = IFIX[ZNUM - NUM(I) x BUFFER x
   MNSHP (I)/ [.95 x 1000) + .5]

The IF statement in #3 above determines which condition governs. If the system is MNSHP constrained, the program immediately jumps to 231 and computes the kicker-ISIZE(I,2). If the system is LIMIT controlled, the program will set ISIZE(I,1) equal to LIMIT and redefine RDTRIP, TBA, and ZNUM.

From these redefined parameters ISIZE(I,2) for a LIMIT controlled condition can be computed.

After ISIZE(I,2) is computed, both sub-branches join and a check is made on the size of the kicker-ISIZE(I,2) -- at statement 232.

232 -- IF [ISIZE(I,2) .GE. 30] go to 204

This statement checks to see if ISIZE(I,2) is greater than or equal to 30,000 tons. Thirty thousand tons is used as a lower acceptable limit for transport sizes. If this lower limit is met, the loop will be incremented by 1 and the next mineship system determined. If the lower limit is breached, the program will go to Branch 3.

Branch 3 - Branch 3 will first set ISIZE(I,2) equal to 30 thousand tons.

ISIZE(I,2) = 30

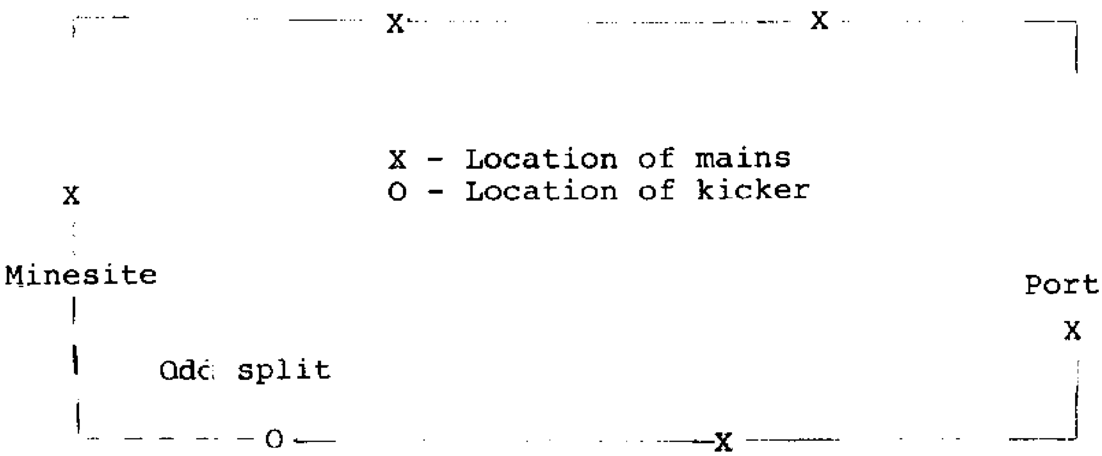
From this point, the sizes of the other ships will be determined as follows:

FILL = 30000 x .95/SRWO(I)
DIST = FILL x SPD x 24
SPLITS = (2 x OWDIS - DIST)/NUM(I)
COVER = SPLITS/(SPD x 24)
ISIZE(I,1) - IFIX[COVER x SRWO(I)/(.96 x 1000) + .51

The parameters FILL, DIST, SPLITS, and COVER are all redefined using the 30 thousand ton kicker as the overriding constraint on the system. The other ships in the system are determined around the kicker. By using the kicker and N other equal sized ships, a round trip track of N equally spaced ships (N regular splits) and one unequally spaced ship (the kicker) is created. The one unequal spacing is referred to as the odd split.

Figure C-1

Branch 3 Graphical Representation



Typical Regular Split

— — —

The rectangle represents the total roundtrip track of the transport ships. The dotted line represents the odd split. The odd split is the distance corresponding to the time it takes for the mineship to mine enough to fill the 30 thousand ton kicker. This time is referred to as 'FILL.' The distance of the odd split is DIST. The regular splits are equal in length. They are equal to the total distance of the track minus the odd split, divided by the number of 'mains.' Functionally represented, the length of the regular splits are:

(2 x OWDIS - DIST)/NUM(I).

COVER is the amount of time it takes for the transport ships to travel these regular splits. During the time COVER, an amount of ore

COVER x SRWO(I)

is mined by the mineship. This amount divided by .9 (to allow for the deadweight of stores, personnel, etc.) is the required size of the mains.

III. Cost Estimation Section

The Cost Estimation section is composed of Capital and Operating Costs. They are as follows:

A. Capital Costs

1. Ship Costs
2. Slurry System Costs

B. Operating Costs

1. Fuel Costs
2. Maintenance and Repair Costs
3. Labor
4. Insurance
5. Miscellaneous, Subsistance and Stores
6. Layup

Each of these cost components is calculated individually and each can be sensitized using a variable TRSF (I) where TRSF stands for Transport Sector Sensitivity Factor and I is the index of the sensitivity factor. The indices corresponding to each cost component are shown to the left of the component in the table above. These cost components can be sensitized by changing the value of the TRSF vector in the input namelist. For example:

```
&PROJKT TRSF = 1.0, 1.0, 2.0, 3.0, 1.0, 1.0,
               1.0, 1.0, 1.0 &END
```

OR

```
&PROJKT TRSF(3) = 2.0, TRSF(4) = 3.0, &END
```

Both change the value of fuel costs to twice the baseline value and change maintenance and repair to three times the baseline value.

A. Capital Costs

The Capital Costs are divided into the costs of the ships and the cost for the slurry handling system. By far, the bulk of the costs are made up of ship costs.

1. Ship Costs

The costs of the transport ships required for each mineship are the sum of the costs of the 'mains' and the cost of the 'kicker' if one exists. They are designated as:

SCST1(I) - ship cost of 'mains'
SCST2(I) - ship cost of 'kicker'
SCST (I) - sum of 'mains' and 'kicker'

The program loops through NMSH times to sum up over all SCST(I) to obtain a total capital ship cost.

The costs can be calculated using either foreign or domestic construction costs. The program is set initially to calculate foreign costs but can be easily changed by setting the value of YARD in the input to any integer value other than 1.

The cost of foreign built ships is calculated as:

$$SCST1(I) = ([.0130 \times ISIZE(I,1^2] - [5.40 \times ISIZE(I,1)] + 627) \times NUM(I) \times ISIZE(I,1) \times 1000$$

$$SCST2(I) = ([.0130 \times ISIZE(I,2)^2] - [5.40 \times ISIZE(I,2)] + 627) \times ISIZE(I,2) \times 1000$$

The cost function is in the form of a parabola. The curve calculates the cost of a ship in dollars per deadweight ton as a function of deadweight tonnage. This is then multiplied by the deadweight tonnage, the number of ships of that tonnage [NUM(I)] and the factor 1000 to put the cost in terms of total dollars. The cost function for SCST1 is the same as the function for SCST2 except that the factor NUM(I) is not involved in the SCST2 calculation since there can only be one kicker per transport system.

The costs for ships built in American shipyards are:

$$SCST1(I) = ISIZE(I,1)^{-5.34} \times 5064 \times ISIZE(I,1) \times NUM(I) \times 1000$$

$$SCST2(I) = ISIZE(I,2)^{-5.34} \times 5064 \times ISIZE(I,2) \times 1000$$

The cost calculations for ships built in American shipyards are basically the same as for foreign yards except that a different dollars per deadweight ton cost curve is used. The cost curve for dollars per deadweight ton for American built ships is in an exponential form given in a general sense by:

$$y = Ax^r$$

where y is $/DWT, A is the constant 5064, r is the power -.534 and x is the independent variable ISIZE.

After SCST1(I) and SCST2(I) are calculated, using either foreign or American construction costs, the program will consolidate them into a cost given in millions of dollars.

SCST1(I) = (IFIX[SCST1(I)/10000 + .5])/100.
SCST2(I) = (IFIX[SCST2(I)/10000 + .5])/100.

SCST1(I) and SCST2(I) are then added to give a total capital cost for ships servicing MNSHP(I):

SCST(I) = [SCST1(I) + SCST2(I)] x TRSF(1)

2. Slurry System Cost

The slurry system cost is calculated to be 1.8 million dollars. This includes 18 pumps at $64,900 per pump. Each pump is estimated at about 7000 GPM, pumping against a 60 foot head (tank depth plus friction and valve losses) and requires a 105 H.P. driver. The total pump cost is $1.17 million. The remainder of the $1.8 million is attributed to piping, valves, couplings, installation and other major pipeline components.

B. Operating Costs

The operating costs are divided up into fuel, maintenance and repair, labor, insurance, miscellaneous, stores and subsistence costs. There is also a category called layup costs which refers to those costs incurred in just maintaining the transport system whether the operation is actually underway or not.

1. Fuel

Fuel costs (FUEL) is calculated as a function of ship size.

$$FUEL1 = NATE^{[-.00862 \times ISIZE(I,1)} \times ISIZE(I,1) \times NUM(I)$$

$$FUEL(2) = NATE^{[-.00862 \times ISIZE(I,2)]} \times ISIZE(I,2)$$

where NATE is the value of the exponential function 'e.' The total fuel cost is given by :

$$FUEL(I) = [7.83 \times WYS \times SPD \times (FUEL1 + FUEL2) * TRSF(3)/1000000$$

7.83, WYS and SPD are common factors to FUEL1 and FUEL2. Fuel costs are calculated as a function of \$/deadweight ton/day/knot. The function is of the form:

$$y + Ae^{-bx}$$

where:

$A = 7.83$

$x = ISIZE(I,1)$ or $ISIZE(I,2)$

$b = .00862$

Therefore costs are actually:

$$FUEL = 7.83e^{-.00682 \times ISIZE} \times WYS \times SPD.$$

The final equation for FUEL(I) is obtained by summing FUEL1 and FUEL2 and applying the common factors in the final form.

2. Maintenance and Repair

Maintenance and repair (MANDR) is calculated as a function of the capital cost of the ship.

$$MANDR1 = [-.00018 \times ISIZE(I,1) + .066] \times SCSTL(I) \times 1000000$$

$$MANDR2 = [-.00018 \times ISIZE(I,2) + .066] \times SCST2(I) \times 1000000$$

The function in brackets calculates a percentage of the total capital cost of the ship which is then multiplied by the cost of the ship and the number of ships of the same cost. The total MANDR is given as;

MANDR(I) = (MANDR1 + MANDR2) x TRSF(4) + [.06 * SLURRY * 1000000) * TRSF(2)]

where .06 x SLURRY * TRSF(2) is the annual maintenance and repair charged to the slurry system.

3. Labor

Labor costs (LABOR) can be calculated using either foreign crew costs or American crew costs. The program is set initiatly to foreign costs but can be changed by changing the value of CREW in the input to any integer value other than 1.

The labor costs are considered constant for any sized ship. Therefore the total labor cost is just a function of the number of ships used.

Foreign Crews: LABOR(I) = 1,800,000 x TRSF(5) x [NUM(I) + ONE]/1000000.

Domestic Crews: LABOR(I) = 3250000 x TRSF(5) x [NUM(I) + ONE]/1000000.

where ONE is equal to the value 1 if a kicker [an ISIZE(I,2)] exists and is equal to zero if a kicker does not exist. The value of ONE is established in the ship cost section by the equation;

IF [SCST2(I) .EQ. 0] ONE = 0

4. Insurance

Insurance costs (INS) are calculated as a function of size which in turn reflects the cost of the ship(s).:

INS1 = [12132 x ISIZE(I,1) - 72794] X NUM(I)

INS2 = [12132 x ISIZE(I,2) - 72794] x ONE

INS(I) = (INS1 + INS2) x TRSF(6)/10000000.

5. Miscellaneous, Subsistence, Stores

Miscellaneous, subsistence, and stores (MISC, SUBSIS, STORES) costs are all considered constant for any sized ship. Therefore the total miscellaneous, subsistence, and stores costs are only a function of the number of ships.

MISC(I) = 225000 x [NUM(I) + ONE x TRSF(7)]/ 1000000.
STORES(I) = 235000 x [NUM(I) + ONE x TRSF(8)]/1000000.
SUBSIS(I) = 150000 x [NUM(I) + ONE X TRSF (9)]/1000000.

6. Layup Costs

Layup (LAYUP) is defined as a fraction of each of the component operating costs:

LAYUP(I) = .25 x INS(I) + .1 x [LABOR(I) + SUBSIS(I)] + .75 x STORES + MISC(I) + MANDR(I).

And finally to reduce to millions of dollars:

LAYUP(I) = (IFIX[LAYUP(I) x 100 + .5])/100.

The program will continue through the loop calculating all capital costs (I) and all operating costs (I) as I ranges from 1 to NMSH.

C. Total Capital and Operating Costs

After the cost estimation loop has been completed, another loop is employed to consolidate the costs to be incorporated into the main program. This is accomplished by the use of the accumulating storage variables:

CAPCST(4,1), the ship capital cost and
OPCST(4,1) through OPCST(4,6), the various operating costs.

All of these accumulating storage variables are initially set to zero. CAPCST(4,2) is the slurry capital cost and is not an accumulating variable with regard to the number of ships used. It is therefore not part of the consolidation loop.

The loop proceeds NMSH times incrementing I each time from I = 1 to NMSH.

DO 205 I = 1, NMSH	
CAPCST(4,1) = CAPSCT(4,1) + SCST(I)	Ship cost
OPCST(4,1) = OPCST(4,1) + FUEL(I)	Fuel cost
OPCST(4,2) = OPCST(4,2) + LABOR(I) + .67 x MANDR(I)	Labor cost
OPCST(4,3) = OPCST(4,3) + STORES(I) + SUBSIS(I) + .33 x MANDR(I)	Materials cost
OPCST(4,4) = OPCST(4,4) + INS(I)	Fixed cost
OPCST(4,5) = OPCST(4,5) + MISC(I)	Miscellaneous Cost
OPCST(4,6) = OPCST(4,6) + LAYUP(I)	Layup cost
205 CONTINUE	
CAPCST(4,2) = SLURRY * TRSF(2)	

In the above loop, MANDR is divided into MANDR related to materials and MANDR related to labor. MANDR related to materials is considered to be one third of the total MANDR. Two thirds of the total MANDR is attributed to labor.

IV. Data Base

The following section gives all the main data used to determine the cost curves for the cost estimation. The data was obtained from trade journals or by direct contact with industry people. The data is presented in such a way that the reader can see it directly and also follow the derivations of the cost curves. After each curve is stated and the derivation given, there is a graph of the cost function including the original data base points so that a comparison can be made. The data are referenced at the end of Appendix C. This is given at the end of the report.

A. Capital Costs

As stated earlier on, the capital costs are divided into the ship costs and the slurry system costs. The ship costs were determined from a curve constructed from a number of point sets of size versus cost. The slurry system cost was determined by calculating the required pump size and number of pumps required and then obtaining a price estimate on that size of pump. An estimate of the required piping and support equipment was then made and added to the pump cost.

1. Ship Costs

SCST1 = Ship cost of 'mains'
SCST2 = Ship cost of 'kicker'

The ship cost functions calculate dollars per deadweight ton as a function of deadweight tonnage. This figure is then multiplied by the deadweight tonnage and the number of ships of the same size. SCST2 is calculated the same way as SCST1 except the factor NUM(I) is not involved.

SCST(I) is the sum of SCST1 and SCST2.
DATA SET C-1

Costs from Japanese shipyards. Based on contracts of December 1976 and January 1977 for bulk carriers and OBO's.

COST/DWT($)	SIZE (1000 DWT)	
418.7	28.5	
397	24	
505	25.3	
386	26.5	
343.8	23.8	
386	26.5	
451	38.5	
288	84	
434	25.5	
456	38	
451	38	
189	119	
185	114	(2)

An additional point was obtained from Calmar Shipping, Baltimore, Maryland;

COST/DWT($)	SIZE (1000 DWT)	
300	74	(3)

When plotted, the overall configuration is that of a parabola. Due to the wide amount of spread in the lower regions (20-30 thousand ton range) a conservative estimate of $500 per deadweight was assumed and used as a fixed point for calculation of the cost curve. The other two points used to determine the parabola were;

$300/DWT	@	74,000 DWT
$115/DWT	@	115,000 DWT

It was felt that the degree of spread in the lower regions and the lack of data in the higher regions did not suggest the need for a non-linear least squares computation. The function was computed as follows;

$$500 = a(25)^2 + b(25) + c$$
$$300 = a(74)^2 + b(74) + c$$
$$185 = a(115)^2 + b(115) + c$$

The constants, a, b, c are determined to be:

$a = .0130$

$b = -5.40$

$c = 627,$

yielding the equation;

$$\text{ship cost} = [.0130(\text{size})^2 - 5.40(\text{size}) + 627] \times \text{size}$$

Some sample points are;

SIZE (1000 DWT)	$/DWT
30	476
40	431
50	390
60	350
70	312
80	278

The sample points are plotted in Figure C-2,

DATA SET C-II, Costs from American Shipyards
Sample Points[4]

These costs were derived form the Dames and Moore study, March, 1977. (4)

COST/DWT ($)	SIZE (1000 DWT)
660	43
1000	22
585	56
853	30
504	74
421	104.5
549	63
448	92.4
626	49.5
822.5	31
596	51
664	45
644	48

The cost curve is derived from a linearized log-log plot that is of the form;

$$Y = mX + b$$

where

$Y = \ln y, \quad y = \text{cost/DWT}$

$X = \ln, \quad x = \text{DWT}$

After the linear equation is derived using the logarithms of x and y both sides of the equation are taken to the base 'e' to give;

$$e^{\ln y} = e^{m \times \ln (x) + b}$$

$$y = e^{m \times \ln (x)} \times e^{b}$$

$$y = (x)^{m} \times A$$

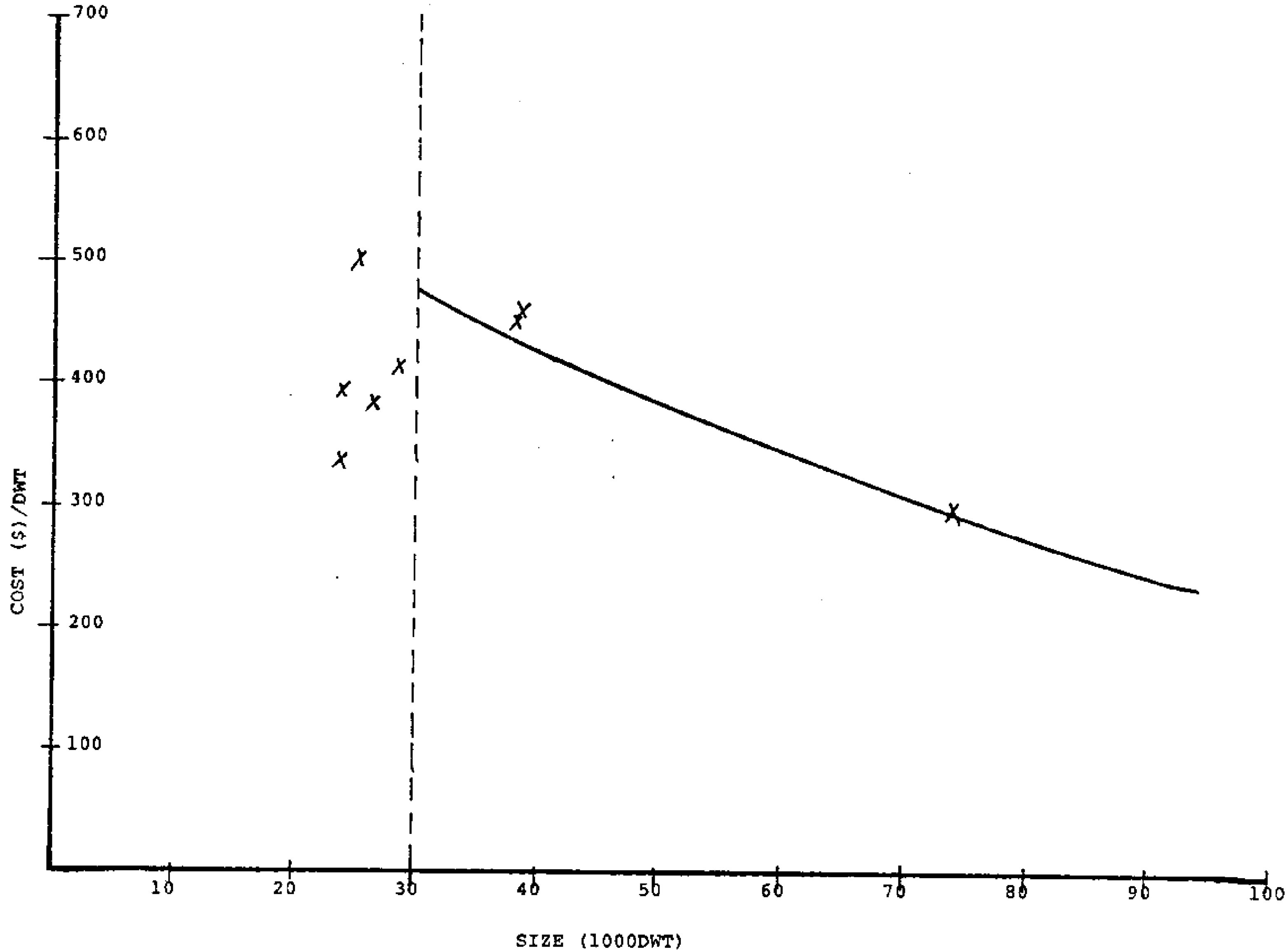


Figure C-2
Foreign Shipyard Construction Costs

where

$A = 5064$

$m = -.534.$

Finally, the equation yields:

$$\text{cost/DWT} = \text{size}^{-.534} \times 5064$$

and total ship cost:

$$\text{cost} = \text{size}^{-.534} \times 5064 \times \text{size}.$$

The sample points of costs from American shipyards are plotted in Figure C-3.

2. Slurry System Cost

As stated in the main text, the slurry system cost is derived from the cost of the pumps, motors, pipeline components and installation charges. This was calculated assuming one motor per pump and adjusting the base pump cost for stainless steel plating. The pump size was calculated by knowing the maximum load of the system. The maximum load is assumed to be 64,000 tons. This figure was used because it is .8 (the baseline buffer condition) times the capacity of an 80 thousand ton mineship. Eighty thousand tons appears to be about the maximum size being presently considered.

Using a settling velocity of 3 fps. for the nodules and an estimated forward velocity of 5 fps. for the water, in a two-foot diameter pipe, the mass rate of flow can be calculated. This figure gives the tonnage rate of flow of the nodules and the equivalent in GPM.

The flow calculations were made using a slurry specific gravity of 1.3. From the mass rate of flow, the required horsepower can be calculated.

Various combinations of pumps were checked for the resulting 'in-port-times.' Nine pumps running at about 7000 GPM, equivalent to about 390 long tons per hour per pump,

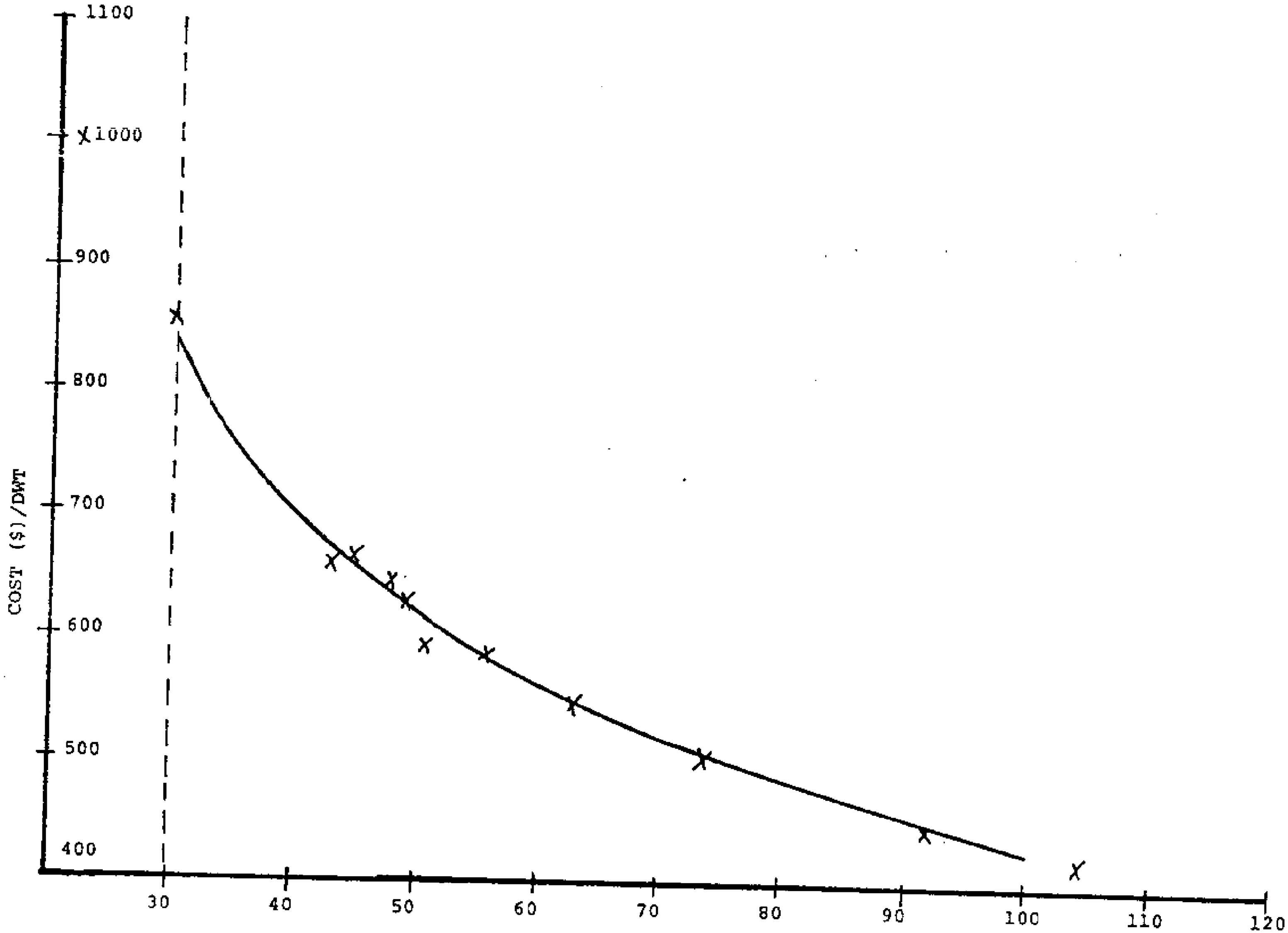


Figure C- 3
American Shipyard Construction Costs

will unload 64,000 tons in .76 days. This is below the assumed maximum of one day and leaves some room for slowdown.

Each pump would require a 105 H.P. motor. The motor costs are incorporated into the pump cost.

DATA SET C-III - Pump Cost Calculations[5]

C/H Factor = 7000 gpm x 60' x 14.7/34 (PSI/FOOT) =
181,000

Base Cost = $6200/pump

Field Materials Factor = .696

Direct Field Labor Factor = .671

Freight and Insurance Factor = .08

Indirect Cost Factor = .757

Bare Module Cost = 3.204 x Base Cost
= 3.204 x $6200
= $19,900

Stainless Steel Plating
Cost Factor = 1.93

Plated Cost = 1.93 x Bare Module Cost
= 1.93 x $19,900
= $38,400

Updated Cost Index[6] = 1.69

1976 Cost = 1.69 x $38,400
= $64,900

Total Cost for 18 pumps = 18 x $64,900
= $1,168,200
= $1.17 million

Yard Pumping and Storage Costs[7] = $373,000

Updated Cost Index[8] = 1.69

Updated Yard Pumping and Storage Costs = 1.69 x $373,000
= $.63 million

Total Slurry System Capital Cost = $1.17 + $.63(million)
= $1.8 million

B, Operating Costs

The deviations of the cost curves for each of the component operating costs are given in this section,

1, Fuel

Fuel costs are calculated form a regression curve that is plotted as a function of $/day/DWT/knot vs. DWT, The curve was derived from the data of DATA SETS C-IV and C-V.

DATA SET C-IV, Oil Prices[9]

Redwood Sec,	Int #	Added Cost $/bbl	bbl/ton
1000	10	,76	6.9
1200	12	,65	6.8
1500	15	,50	6.8
2000	20	,33	6.7
2500	25	,24	6.6
3000	30	,14	6.6
3500	35	.07	6.5

The base cost used is $10.90 per BBL, West Coast as of March 1977.

— — —

DATA SET C-V, Typical Fuel Consumption[10]

1000 DWT	Speed	Ton/Day	Tons/Day/ Knot/1000 T	$/Ton	$/Day/ Knot/1000 T
22	14.5	28	,0877	80.45	7,05
28	15	29	,0690	76.40	5.27
34	16,5	38,4	,0684	76.40	5.22
38	15	40	.0702	80,45	5.68
30	15	38	,0844	76.40	6.45
82	16	70	,0530	71,30	3.78
86	15.65	72.3	,0537	80.45	4.32
98	16	64	.0408	80.45	3,28
98	16	66,2	.0422	76,40	3.22
56	15	47.1	,0561	80,45	4.51
78	14.5	64	.0566	78.50	4.44
70	16.25	67	.0569	71.30	4.20

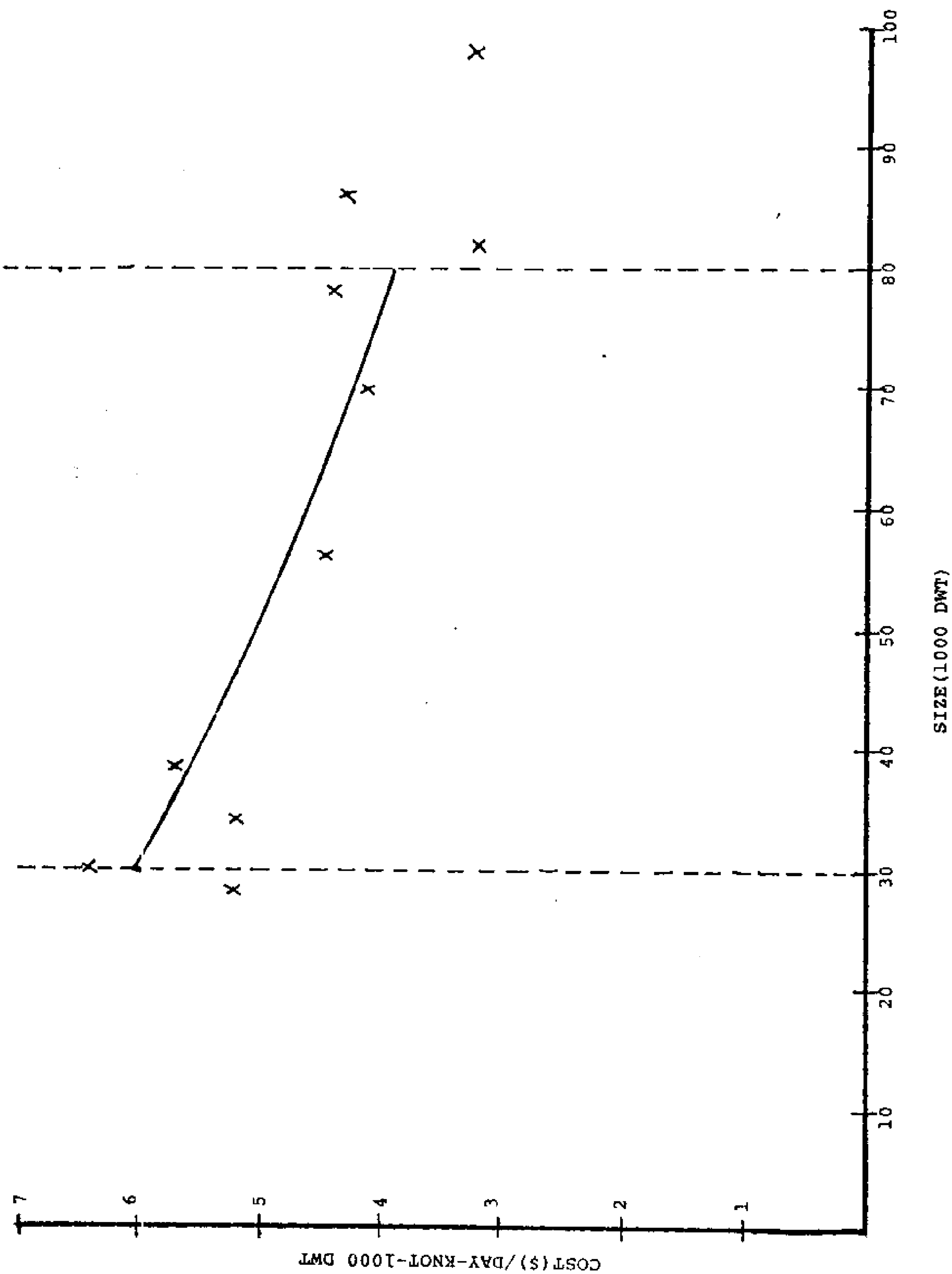


Figure C- 4
Fuel Consumption Costs

2. Maintenance and Repair[11]

Maintenance and repair is determined using a sinking fund schedule. The total maintenance and repair cost over a given period is defined as that amount that would be available at the end of the period if a set principle were invested at a given interest rate for each year of that period.

For instance, for a 74,000 ton vessel, the maintenance and repair over a ten year period would be that amount accumulated after ten years if $8,000,000 were invested at 8% for each of those ten years. Or,

$$800{,}000 \times \frac{(1 + .08)^{10} - 1}{.08} = \$11{,}589{,}250.$$

This kind of scheduling is done to shift costs toward the end of the period. Maintenance and repair costs are low for a new ship in its first years of service and tend to increase dramatically toward the end of its service life.

In order to establish an annual equivalent cost for use in the main program the accumulated amount is divided by the period. For the 74,000 ton vessel, the annual maintenance and repair is taken to be:

$11,589,250/10 = $1,158,925.

The capital cost of this vessel is $22,000,000 and the fraction of capital cost attributed to annual maintenance and repair is therefore:

$1,158,925/22,000,000 = .05255.

For a 40,000 ton vessel, the figures are $7,000,000 over ten years at 8%:

Total = $10,140,594
$ per year = $1,014,059
Capital cost = $17,280,000
Fraction of capital cost = .05868

A straight line interpolation was done between these two points and extrapolated outward.

The curve and the calculations are shown in Figure C-5.

3. Insurance[12]

Insurance costs are calculated using a straight line approximation between ships of 40 and 74 thousand tons and extrapolating outward. Below 40 thousand tons the insurance costs remain fairly constant. Because the model does not go below 30 thousand tons, the straight line approximation is considered valid down to this range.

The dotted curved line on the insurance cost graph (Figure C-6) shows what the actual cost curve would look like below 30 thousand tons. It intersects the cost axis at \$100,000 (not shown on graph). This intersection refers to a zero size cost of \$100,000 per year.

The insurance figure calculated gives actual insurance premiums paid plus reserve -- to cover those claims not insured.

4. Labor, Stores, Subsistence and Miscellaneous

These costs were determined from the base cost of each of the above components per ship. They are:

Labor
- Foreign = \$1.8 million/ship
- Domestic = \$3.25 million/ship[13]

Stores = \$234,000/ship[14]

Subsistence = \$150,000/ship[15]

Miscellaneous = \$225,000/ship[16]

V. Variables and Initial Conditions

This section gives a list of all the user defined variables, their code name, initial value, description and range as well as a list of all variables used in the transport sector.

Table C-2

User Defined Variables

Variable Code Name	Definition	Initial Value	Bounds of Validity
SPD	Speed of transport vessels	15.knots	14,5 - 16.25 knots
NMSH	Number of mineships	1	any integer number
BUFCAP	Maximum mineship size	60(MDWT)	any integer number
BUFFER	Decimal fraction of mineship size to be allocated to nodule storage	.8	any real number less than or equal to 1.0
OWDIS	One way distance to port	1750. naut. miles	any real integer
LIMIT	Size limit at a given port	80(MDWT)	any integer number
SLURRY	Slurry system capital cost	$1.8 million	dependent upon system used
YARD	Determines whether foreign or domestic ship costs are to be used	1	any integer number other than 1 will give domestic building costs
CREW	Determines whether foreign or domestic crew costs are to be used	1	any integer number other than 1 will give domestic crew costs

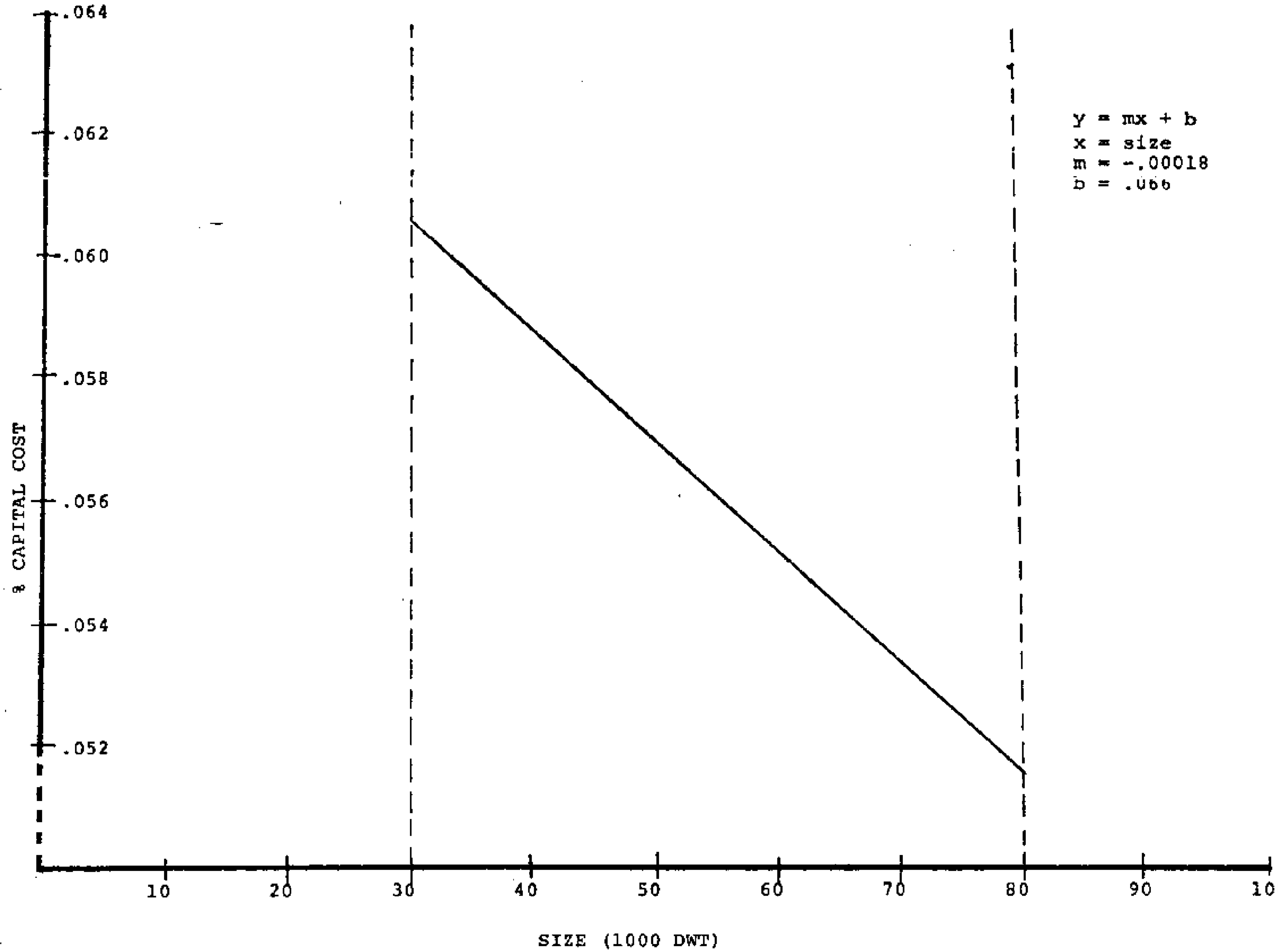


Figure C- 5

Maintenance & Repair Costs

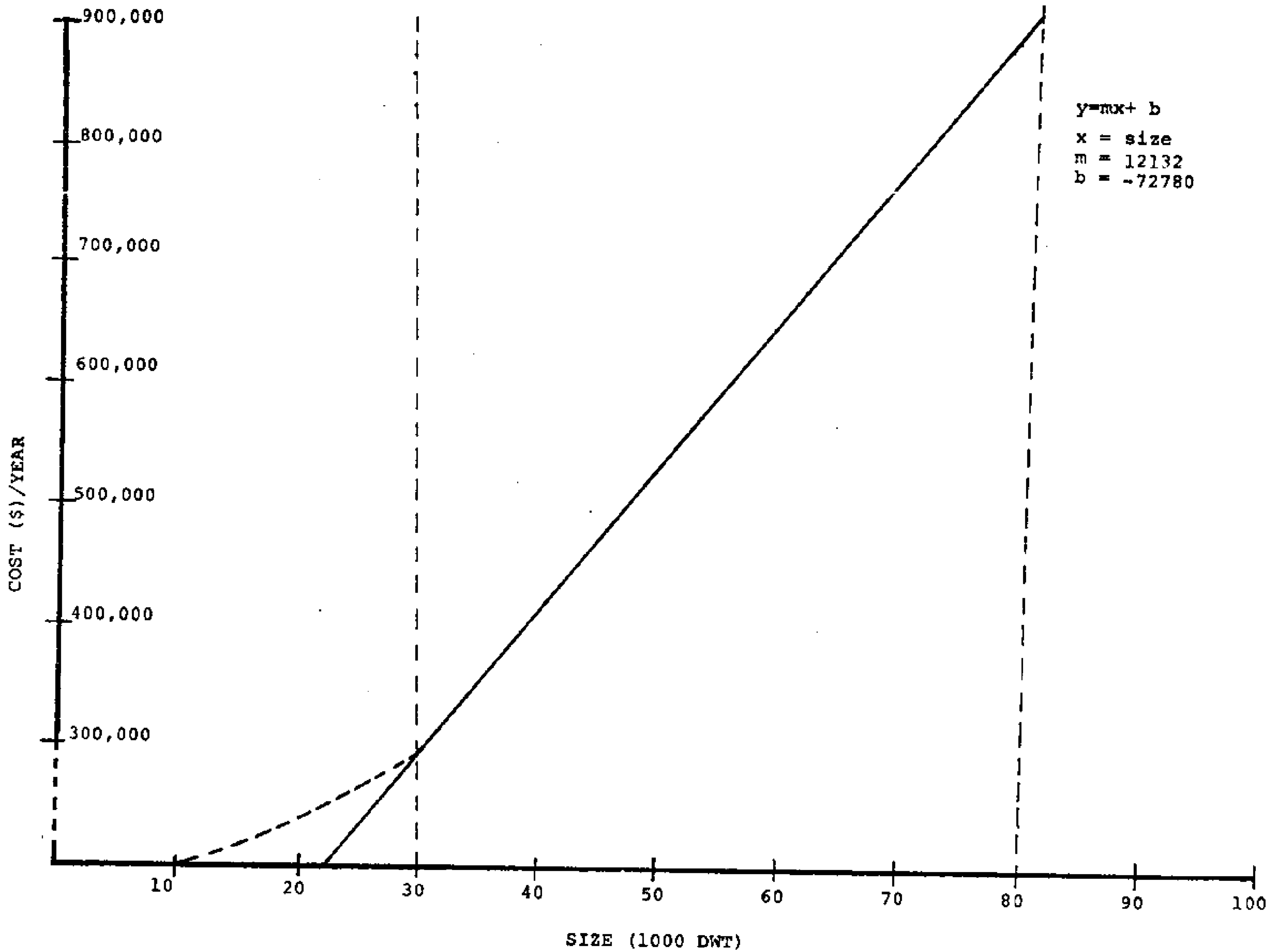


Figure C-6
Insurance Costs

Table C-3

List of All Variables

ARO - Annual rate of ore production (dry short tons).

BUFFER - Fractional multiplier to reduce mineship actual size to a desired effective size. For example, a 60 thousand ton mineship with a BUFFER factor of .8 would have a .8 x 60 = 48 thousand ton desired effective size.

WYS - Work days per year.

OWDIS - One way distance to port.

DRWO - Daily rate of wet ore production (wet long tons).

SRWO - Daily rate of wet ore production per minsehip (wet long tons).

RDTRIP - Roundtrip time to port and back to minesite.

NMSH - Number of mineships.

BUFCAP - Maximum actual mineship size.

TBA - Time between arrivals at mineship.

SPLITS - Distance between transport vessels.

LIMIT - Upper limit size of transport vessels.

ZNUM - Number of ships of size [BUFFER x MNSHP(I)] required to service MNSHP(I).

NUM - Next lowest integer from ZNUM.

FILL - Time required to fill a 30,000 DWT transport ship at SRWO.

DIST - Distance that ships can travel during FILL.

COVER - Time required to cover splits.

ONE - The term ONE is used as either the value 1 or the value 0.

If a 'kicker' exists then ONE = 1. If a 'kicker' does not exist ONE = 0.

The term 'kicker is used to denote an auxilliary vessel -- one of a smaller size than the main transports. A kicker is used when a given number of equal sized ships are not adequate, by themselves, to do the job. In these cases, an extra, smaller ship is added to the system.

Appendix C Notes

1. Draft Report: A Description of Transportation and Waste Disposal Systems for Manganese Nodule Processing, Prepared by Dames & Moore, Salt Lake City, Utah, and Benjamin V. Andrews, Menlo Park, California for U.S. Department of Commerce, NOAA, Office of Marine Minerals, March 16, 1977, p. 3.0-8.

2. "Shipping Statistics and Economics," Drewry Ltd., Shipping Consultants, London, January 1977 and February 1977.

3. Calmar Shipping Co., New York, New York.

4. Dames & Moore, Andrews, p. 3.0-8.

5. Kenneth Guthrie, "Capital Cost Estimating," Chemical Engineering, March 24, 1969.

6. Marshall & Stevens Equipment Cost Index.

7. Guthrie.

8. Marshall & Stevens Equipment Cost Index.

9. Exxon Marine Fuels Bulletin, March 1977.

10. Bulk Tanker Register, 1977.

11. Calmar Shipping.

12. Mr. Benjamin Andrews, Ocean Transportation Consultant and Calmar Shipping Co. (Independently).

13. Ibid.

14. Calmar Shipping

15. Ibid.

16. Ibid.

APPENDIX D, COST ESTIMATION OF THE PROCESSING SECTOR

I. Introduction

The processing sector of the study's model of a deep ocean mining operation includes all operations from the port facility that receives the nodules to the final disposal of the tailings at the waste disposal site. The general structure of the processing sector is described in Section D of Chapter III and the structure is summarized in Figure D-1. The sector is divided into five sub-sectors: processing equipment, utilities, site development, buildings, and waste disposal. The cost of each sub-sector is determined separately, complete with engineering and contingency fees and indirect construction costs. These sub-sector costs are later used in the financial analysis section in determining the attractiveness of deep ocean mining as an investment.

— — —

Figure D-1. Structure of the Processing Sector

Material Preparation Dry & Reduce Leach & Wash Ion Exchange Electrowinning Reagent Recovery		Equipment	Total Processing Investment
Gasification Power Plant Power Distribution Steam Plant Steam Distribution Cooling Tower		Utilities	
Wharf Shore Facilities Land	Port Cost	Site Development	
Storage Cost Yard Cost	Development		
Rail Transport Slurry Transport	Transport		
Land Purchase Land Preparation	Land		
Buildings		Buildings	
Waste Transport Land Purchase		Waste Disposal	

The computer program is structured to analyze various processing alternatives. The information that is required by the program is a specification of all units of the processing system, with cost-capacity relationships and energy and material requirements. The cost of the equipment sub-sector is determined from the cost-capacity information, and other information that describes the rest of the processing sector. The energy and material requirements are used to determine the investment required in utilities. The cost of processing equipment is used to determine the investment in buildings, which is assumed to be proportional to the equipment investment. The costs of the site development and waste disposal sub-sectors do not vary with changes in processing equipment or specifications. Any changes in these areas must be specified separately.

In this appendix, the method of capital cost estimation used in this model is explained in Part II. The operating costs are detailed in Part III. Part IV includes a description of the ammonia leach system used in the model, as well as a summary of the initial values of all input variables in the processing sector. Part V is composed of specification sheets that describe all components of the processing sector.

II. Capital Cost Estimation

The capital costs of the sub-sectors are determined by different methods, but the final results must be consistent with the other sub-sectors. The cost of each sub-sector is composed of four elements: the direct cost of equipment and development, the indirect construction costs, the contractor fee, and a contingency fee. The determination of the direct costs is particular to the individual sub-sectors and discussed below.

A. Indirect Costs and Fees

Indirect costs are not directly attributable to the individual sub-sectors, and so are allocated to each sub-sector based on the investment in that sub-sector. Indirect costs include the cost of freight, insurance, taxes, construction overhead, and contractor engineering costs. The elements of the project indirect costs are shown in Figure D-2.

— — —

Figure D-2. Elements of Project Indirect Cost[1]

Sales, other Taxes U.S. Freight, Packing, Ins. Ocean Freight Marine Insurance Import Duties	Freight, Insurance, and Taxes	Total Project Indirect Costs
Fringe Benefits Labor Burden Field Supervision Temporary Facilities Construction Equipment Small Tools Misc. Field Costs	Construction Overhead	
Project Engineering Process Engineering Design and Drafting Procurement Home Office Construction Office Overhead	Contractor Engineering	

— — —

In this model the indirect costs are estimated to be proportional to the capital investment in direct cost. The ratio of direct cost plus indirect cost to the direct cost alone is given by the variable FID.

The contingency fee is included in the estimation of the processing plant capital cost in order to account for items that are not directly acounted for in the structure of the model.[2] This fee is based on the sum of direct and indirect construction costs. It is represented by the variable CONFEE.

The contractor fee is based on a fraction of the total investment.[3] The value of the contractor fee is given by the variable ENGFEE.

The total cost of the sub-sector is determined from the direct cost, FID, CONFEE, and ENGFEE. For example, the total investment in the equipment sub-sector is represented by the variable ECMOD, and the direct cost of the sub-sector by EC. The sub-sector cost is determined by the equations:

$$ECMOD = EC \times TMF; \text{ where}$$

$$TMF = FID \times [1 + ENGFEE + CONFEE].$$

At this point in the capital cost estimation procedure the structure begins to diverge. The sub-sectors of the processing sector have characteristics that require individual consideration so each sub-sector cost estimate is made in a manner consistent with the structure of the sub-sector.

B. Processing Equipment

The largest sub-sector of the processing sector is the process equipment sub-sector. The processing equipment is important not only because it is the major component of the capital cost of the entire sector, but also because the material requirements of the equipment determine the size of the utilities sub-sector and the investment in the buildings sub-sector as well. Because of the effect on the utilities sub-sector, the processing equipment cost is the first to be calculated. As part of the calculation, the energy and material requirements for the sub-sector are determined. The results of the process equipment cost estimate provide not only the investment in that sub-sector, but serve as input to the utilities and buildings cost estimates.

The cost of the equipment sub-sector (EC) is the sum of the costs of the individual items of equipment (or groups of equipment) that comprise the sub-sector. The individual costs [COST(I)] are determined from power law estimation formulae of the form:

$$COST(I) = BASE(I) \times SIZE^{EXP(I)},$$

where BASE(I) and EXP(I) are inputs to the program that describe the cost-capacity relationship of the item of equipment. The variable SIZE is the processing rate of the item, expressed in tons per hour. SIZE may have either of two values: the rate of ore being processed by the plant, or the rate of recovery of nickel, copper, and cobalt. The value of SIZE is specified in the input data for each item by the variable TYPE(I). When TYPE(I) is '0' the equipment processes ore, and when TYPE(I) is '1' the equipment processes the recovered metal.

In the model the value of SIZE is determined by one of two equations. If the variable TYPE(I) is equal to zero then:

$$SIZE = HR,$$

where HR, the hourly rate of nodule processing in dry short tons, is given as:

$$HR = ARO/(WD \times WY).$$

If TYPE(I) has the value of '1' then:

$$SIZE = HR \times TRC,$$

where TRC is the total recovered content of metals from the nodules. This variable is determined from the composition of the nodules and the recovery efficiency of the processing system:

$$TRC = \sum_{I=1}^{3} [COMP(I) \times RE(I)].$$

The index variable "I" is used to specify the values of COMP and RE for nickel, copper and cobalt.

The total direct cost of the sub-sector is given as:

$$EC = \sum_{I=1}^{NN} COST(I)$$

where NN is the total number of equipment items that comprise the sub-sector.

As shown above, the total sub-sector cost, including direct cost and all fees, is given as:

$$ECMOD = EC \times TMF.$$

Calculation of Energy and Materials Requirements. Following the estimation of the cost of an item of processing equipment, the model calculates the energy and materials requirements of the equipment. These requirements are computed from the values of specific consumption that are included in the input data describing the process system. Specific consumption of electricity, steam, fuel, chemical, and chilled water is provided for each item in units of kw-hr, thousands of pounds, millions of BTU's, dollars, and thousands of gallons per ton of material processed, respectively. The power requirement of an item of equipment is given as the product of the specific consumption [P(I)] and the processing rate. The power requirement of the entire sub-sector is given as:

$$\text{POWR} = \sum_{I=1}^{NN} P(I) \times \text{SIZE}$$

At this point in the program the annual energy requirement is calculated for later use in the operating cost estimation section. The annual energy requirement of a single item is represented by the variable POW(I). This is calculated from the specific consumption and the annual rate of material processing (AR). AR is calculated from the processing rate of the item (SIZE), and the lengths of the work day (WD) and work year (WY). The energy requirement for the entire sub-sector is given as:

$$\text{TP} = \sum_{I-1}^{NN} \text{POW}(I)$$

where:

$$\text{POW}(I) = P(I) \times \text{AR; and,}$$
$$\text{AR} = \text{SIZE} \times \text{WD} \times \text{WY}.$$

The total hourly steam requirement of the sub-sector is calculated from the individual specific consumptions as:

$$\text{STM} = \sum_{I=1}^{NN} S(I) \times \text{SIZE}.$$

In a similar manner the hourly requirements of fuel [SGAS] and of chilled water are given by:

$$SGAS = \sum_{I=1}^{NN} F(I) \times SIZE; \text{ and,}$$

$$CWR = \sum_{I=1}^{NN} CW(I) \times SIZE.$$

The annual requirement of chemicals is determined here for later use as:

$$TCH = \sum_{I=1}^{NN} CHEM(I)$$

where:

$$CHEM(I) = CH(I) \times SIZE.$$

C. Utilities Sub-Sector

The utilities sub-sector of the processing plant includes a coal gasification plant, a power plant, steam generation facilities, cooling tower, and distribution facilities for power and steam. The cost equations for these facilities are discussed below. Further details about the units and the sources of cost information are provided in the specification sheets at the end of this appendix.

The coal gasification unit is described in the equipment specification sheets at the end of this appendix. The cost of the plant is estimated from the capital cost of a synthetic gas plant proposed by the U.S. Bureau of Mines. The cost of the plant is scaled by a power law function given as:

$$SGCST = 99 \times 10^6 \times (SGAS/9000)^{SGEXP},$$

The variable SGEXP provides scaling of the plant cost when the capacity of the plant is different from the design capacity of 9000 million BTU per hour. The value of SGEXP, which is an input variable in the program, has an initial value of 0.8.

Electric power may either be produced on site or it may be purchased from a commercial power company. In this model the power is generated on site up to a limit that may be specified by the program operator. Above this limit the power is purchased from outside. The cost of the power plant is based on the power plant production rate (PPR), which is given as:

$$PPR = POWR,$$

unless POWR exceeds the power production limit (POWLIM) in which case:

$$PPR = POWLIM.$$

The cost of the power plant is given by:

$$PPCST = 13.75 \times 10^6 \times (PPR/25100)^{.75}.$$

The cost of the steam plant is determined from the hourly steam requirement:

$$BLRCST = 4.87 \times 10^6 \times (STM/520)^{.8}.$$

The cost of the cooling tower is given as:

$$CTCST = 687 \times 10^3 \times (CWR/2.01 \times 10^6)^{0.6}.$$

The cost of distribution facilities for power (PDCST) and steam (SDCST) are proportional to the requirements for these services:

$$PDCST = 158 \times POWR; \text{ and,}$$

$$SDCST = 2570 \times STM.$$

The total direct cost of the utilities sub-sector is the sum of the costs of the individual components:

$$UCC = BLRCST + SDCST + PPCST + PDCST + CTCST + SGCST.$$

The total cost of the utilities sub-sector, including indirect costs and fees, is given as:

$$UMOD = UCC \times TMF.$$

D. Site Development Sub-Sector

The costs of the site development sub-sector are divided into four groups: port facilities cost, land purchase and improvement cost, transport systems cost, and yard development cost. As is shown in Figure D-1, each of these groups is composed of even smaller groups of costs.

The port facility is the portion of the plant that unloads nodules from the transport ships and provides temporary storage until the nodules can be transported to the processing plant. The major components of the port facility are the pier and the dredging associated with the development of a deep water channel, the storage facility for the entire volume of nodules that off-loaded from a single transport ship, and the land on which the facility is located. The cost of the pier and channel preparations is represented by the variable WRFCST. The cost of the storage area and other shoreside development is represented by SHRCST. The cost of the land is the product of the area of the facility (PORTAR) and the price of land on the coast (LAND3). The total cost of the port facility is given by:

$$PRTCST = WRFCST + SHRCST + LAND3 \times PORTAR.$$

The cost of the land for the actual processing plant includes the purchase of the land as well as the cost of the land survey, leveling, grading, and landscaping. The cost of the land is the product of the area of the site (ARST) in acres and the price of land at the site (LAND2). The cost of all land preparations is given in dollars per square yard by the variable PRPCST. The cost per acre is given as 5000 times PRPCST. Thus, the total cost of land purchase and preparation (LNDCST) is given as:

$$LNDCST = LAND2 \times ARST + PRPCST \times ARST \times 5000.$$

The development costs of the site include the construction of storage areas for a one month supply of nodules and coal, and all yard equipment, such as sewer lines, fencing, lighting, fire mains, drinking water distribution, and a well. The storage facilities cost is represented by the variable STRCST, and the yard improvements cost by the variable YRDCST. The total cost of development is given as:

DEVCST = STRCST + YRDCST.

Transportation costs are incurred by the need to transport nodules from the port facility to the plant and by the need to move raw materials into the processing plant and to move finished products out. It is assumed in this model that the nodules are moved in a slurry pipeline from the port to the plant. The cost of this pipeline is determined by the construction cost of a slurry pipeline (SCPM) in dollars per mile of pipeline, and by the area of land for the pipeline right-of-way (LAND4), which is assumed to require six acres per mile of pipeline These costs give the cost of the pipeline in dollars per mile, and this value is multiplied by the length of the line to obtain the total capital cost of the pipeline.

The transportation of materials other than the nodules is done by rail. The cost of a spur line connecting to the main rail system is estimated from the cost of a mile of railway (RLCPM) and the distance to the main rail line (DIS3). The total cost of the transportation system is given as:

TRNCST = RLCPM x DIS3 + SCPM x DIS1 + DIS1 x 6 x LAND4.

The costs of transportation, development and land are summed to obtain the total site cost at the processing plant:

PLTCST = LNDCST + TRNCST + DEVCST.

The total direct cost of the site development sub-sector is given as:

SCC = PLTCST + PRTCST.

The total cost of the site development sub-sector, including indirect costs and fees, is given as:

SMOD = SCC x TMF.

E. Buildings Sub-Sector

The cost of buildings for the processing plant are estimated as a fraction of the total investment in processing equipment.[4] The direct cost of buildings (BLCC) is expressed as:

BLCC = BFAC x EC,

where BFAC is an input variable that may be changed by the program operator if it is so desired.

The total cost of the buildings sub-sector is given as:

BLMOD = BLCC x TMF

F. Waste Disposal Sub-Sector

In this model it is assumed that the wet tailings that leave the processing plant will be moved by a slurry pipeline to a disposal site. The disposal site is a large area of land that will be made into containment ponds as needed to receive the waste. The capital cost of the sub-sector is limited to the cost of the slurry pipeline from the plant to the disposal site and the cost of the land for the disposal site and the right-of-way for the pipeline. All development of the disposal site is done on an annual basis and is considered to be an annual operating cost.

The cost of the slurry pipeline is calculated from the cost per mile for the pipeline (SCPM) and the distance from the plant to the disposal site (DIS2). The cost is represented by the variable WSLCST, which is given as:

WSLCST = DIS2 x SCPM

The cost of land for the pipeline right-of-way is calculated on the basis of 6 acres per mile of pipeline.[5] The cost of land along the right-of-way is represented by the variable LAND5. The cost of land for the disposal site is based on a requirement of 100 acres per year for a system that processes three million dry short tons of nodules per year.[6] The actual annual land requirement is proportional to the processing rate (ARO) and is obtained by dividing ARO by 30,000, which gives 100 acres per year for the rate of three million tons per year. The cost of land for the disposal site is calculated from the annual land requirement, the operating lifetime of the project (KOPS), and the price of land at the disposal site (LAND1). The total cost of land in the disposal sub-sector is given by:

WLDCST = LAND1 x KOPS x ARO/30,000 + DIS2 x 6 x LAND5.

The total direct cost of the waste disposal sub-sector is given as:

WCC = WSLCST + WLDCST.

The total cost of the waste disposal sub-sector is given as:

WMOD = WCC x TMF.

G. Summary

The results of the processing sector capital cost estimation procedure are stored as part of the capital cost array that is used in the financial analysis portion of the model. The costs are stored in units of millions of dollars. The elements of the array are specified by these five equations:

CAPCST(5,1) = ECMOD/1000000;
CAPCST(5,2) = UMOD/1000000;
CAPCST(5,3) = SMOD/1000000;
CAPCST(5,4) = BLMOD/1000000; and
CAPCST(5,5) = WMOD/1000000.

In addition, the total capital cost of the processing sector is calculated for use in the operating cost estimation section. The total capital cost of the sector is represented by the variable PCC, which is given as:

PCC = ECMOD+ UMOD + SMOD + BLMOD + WMOD.

III. Operating Cost Estimation

The operating costs of the processing plant are determined from: 1) material and energy requirements; 2) labor requirements; 3) charges proportional to direct labor cost; and 4) charges proportional to the cost of the entire processing plant. These costs are then grouped into five divisions: energy, labor, materials, fixed, and miscellaneous costs. The structure of the operating cost estimate is shown in Figure D-3.

— — —

Figure D-3. Operating Cost Structure in the Processing Sector

Purchased Electric Power Coal	Energy	Processing Sector Operating Cost
Direct Labor Payroll Overhead Maintenance Labor Indirect Costs	Labor	
Chemicals Operating Supplies Maintenance Materials	Materials	
State Taxes Insurance	Fixed	
Waste Disposal Preparation Slurry Pipeline Operation	Miscellaneous	

— — —

A. Energy and Material Costs

The energy and material requirements of the processing system are determined in the process equipment capital cost estimation section of the program. These requirements are used to determine the annual cost of materials and energy in the processing sector.

Energy is supplied to the processing plant either as electricity or as coal. The annual requirement of electric power is the difference between the power requirement of the plant (POWR) and the power generated by the power plant (PPR) times the number of operating hours per year:

PURPOW = (POWR - PPR) x WD x WY.

The annual cost of purchased power is determined from PURPOW and from the cost per kilowatt-hour of electricity (PP):

APC = PP x PURPOW

Coal is used in three components of the utilities sub-sector: gasification; steam production; and power production. The annual consumption of coal is expressed in short tons per hour by the variable COALRT. This variable is expressed as a function of five variables: the annual requirement of synthetic gas; the annual steam requirement; the energy conversion efficiency of the steam plant; the annual production of the power plant; and the conversion efficiency of the power plant. Also part of the expression are four constants. The first constant (0.066) is the tons of coal required to produce one million BTU's of gas.[7] The second constant (0.0384) is the inverse of the heating value of coal in tons per million BTU. This is based on coal with a heating value of 13,000 BTU per pound.[8] The third constant (0.9) is the heat required to produce 1000 pounds of steam, expressed in millions of BTU's.[9] The final constant (0.00345) is the BTU equivalent of one kilowatt-hour expressed in millions of BTU. The variable COALRT is given as:

COALRT = 0.066 x SGAS + 0.0384 x (.9 x STM/STMEFF
+ PPR x .00345/PPEFF).

The annual cost of coal is determined from the price of coal (COALPR), the consumption rate of coal (COALRT), and the length of the work day and work year:

AFC = COALPR x COALRT x WD x WY.

The cost of reagents and chemicals used in the processing system is computed in the equipment capital cost section of the model. The total cost of chemical in the equipment sub-sector is given by the variable TCH. This value is assigned to the variable for annual chemical cost (ACC) and is included in the computation of the total operating materials cost:

$$AMC = AFC + APC + ACC.$$

B. <u>Labor Costs</u>

Direct operating labor requirement is calculated for three areas of the processing sector: the synthetic gas plant; the electrowinning plant; and the remainder of the processing plant. The annual labor requirement of the gas plant is given by:[10]

$$SGLBR = WY \times 1080. \times (SGAS/9000)^{.25}.$$

The labor requirement in the eletrowinning section is a function of the metal recovered from the nodules (given by the fraction TRC) and is expressed as:[11]

$$EWLBR = 2080 \times (ARO \times TRC)^{.48}.$$

The labor requirement for the remainder of the plant is estimated for each of the major sub-groups of the processing system (except for the electrowinning sub-group) as a function of the daily processing rate [ARO/WY]. The number of sub-groups in the plant is given by the variable NSG, so the labor cost per sub-group is multiplied by [NSG - 1] to obtain the labor for the processing equipment, other than electrowinning. The labor requirement is expressed as:[12]

$$PLTLBR = (NSG - 1) \times 48 \times WY \times \left[\frac{ARO}{100 \times WY}\right]^{.25}.$$

The total annual requirement of labor is given as:

$$TL = SGLBR + EWLBR + PLTLBR.$$

The annual cost of operating labor (exclusive of benefits) is the product of the labor requirement and the average wage:

CL = TL x WAGE.

The cost of supervisory personnel is given as 20% of the operating labor cost:[13]

SUP = .2 x CL.

The direct labor cost (DL) is the sum of the operating labor cost and cost of supervision:

DL = CL + SUP.

C. Costs Proportional to Labor Charges

Payroll overhead includes all benefits to employees other than their salary. The overhead is proportional to the direct labor cost of the plant, and it is estimated by the overhead fraction PAYOHD. The overhead (PO) is given by:[14]

PO = PAYOHD x DL.

Indirect operating costs are also estimated to be proportional to the annual cost of direct labor. The indirect costs (CI) are stimated to be 40% of the direct labor cost.[15]

CI = .4 x DL.

D. Costs Proportional to Capital Investment

The maintenance of the processing sector is estimated to be a constant annual cost that is proportional to the capital investment in the entire sector. The total annual maintenance cost (UPK) is calculated from the sector capital cost (PCC) and the maintenance cost fraction (UPKF):[16]

UPK = UPKF x PCC.

The cost of maintenance includes both materials and labor. In this model it is assumed that the cost of labor comprises two thirds of the maintenance cost and materials cost the remaining one third.[17]

Operating supplies of the processing sector are estimated to be 1.2% of the capital investment:[18]

$$CS = 0.012 \times PCC.$$

Two remaining costs that are proportional to the capital investment are the cost of insurance (PINS) and the annual state and local taxes (STAX). The taxes are calculated from the variable STXRT, which is the state and local tax rate. The cost of insurance is calculated from the variable PINSRT, which is the insurance rate. The two costs are given as:

$$STAX = STXRT \times PCC\text{: and}$$

$$PINS = PINSRT \times PCC$$

These two costs are summed to obtain the total fixed cost of the processing sector:

$$FC = STAX + PINS.$$

E. Miscellaneous Costs

These costs are incurred away from the processing plant, and include the cost of operating the slurry pipelines from the port to the plant and from the plant to the waste disposal site, and the cost of preparing the disposal site to receive tailings from a year's processing of nodules.

The cost of operating the pipelines is proportional to the annual tonnage carried in the lines. It is assumed that the tailings contain most of the material that comprise the nodules, so the annual production rate of nodules (ARO) is used to calculate the operating cost of both pipelines. The operating cost is calculated from the estimated cost of carrying one ton of material for a distance of one mile (SLRYOP). The operating cost of the plant to port line is based on the length of the line (DIS1) and is given as:

$$PPSLTR = DIS1 \times SLRYOP \times ARO.$$

The cost of the plant to disposal site line is calculated in a similar manner for the distance DIS2:

WSTTR = DIS2 x SLRYOD x ARO.

The cost of preparing the disposal site is proportional to the disposal rate, which is assumed to be equal to the annual production rate of nodules (ARO). The area required is based on 100 acres for the disposal of three million tons of nodules, which is equivalent to six tons per square yard.[19] The cost of preparing and lining the disposal site is given in dollars per square yard by the variable PRLNR, and the annual cost of preparing the disposal site is given as:

WSTOP = ARO x PRLNR/6.

F. Summary

As is shown in Figure D-2, the operating costs that are calculated above are grouped into five general classes of operating cost. These classes are the elements of the processing sector operating cost array that is passed on to the financial analysis section of the model. The elements of the array are specified by these five equations:

OPCST(5,1) = (APC + AFC)/1000000;
OPCST(5,2) = (DL + .67 x UPK + PO + CI)/1000000;
OPCST(5,3) = (ACC + OS + .33 x UPK)/1000000;
OPCST(5,4) = FC/1000000; and
OPCST(5,5) = (WSTOP + WSTTR + PPSLTR)/1000000.

In addition, the operating costs of the processing sector are grouped into direct, indirect and fixed costs. These costs are summed to obtain the total annual operating cost of the processing sector. This is done by the following four equations:

DC = AMC + DL + UPK + PO + OS + WSTOP + WSTTR + PPSLTR;
CI = .4 x DL;
FC = STAX + PINS; and
POC = DC = CI = FC

IV. Baseline Conditions of the Processing Sector

The initial conditions of the processing sector model are discussed in two groups in this section. The first group are the parameters that specify the processing method used in the model. The model has been designed to allow a variety of metallurgical processes to be examined, although the present application of the model is limited to a single process. The presentation of data describing the process presently used in the model can serve as a guide for the modeling of other processes for use in the program. The second group of initial values includes all variables, other than those related to the specific metallurgical process, that may be changed by the program operator. These values are tabulated in Table D-4, later in this section.

A. The Metallurgical Process

A variety of metallurgical processes for the recovery of valuable metals from ocean nodules have been developed by the minerals industry.[20] Since the valuable metals contained in the nodules are finely dispersed throughout the structure, hydrometallurgical methods have been developed and have been successful in the recovery of nickel, copper, cobalt, and, sometimes, manganese.[21] The selection of a specific process depends on the decision whether or not to market manganese, on the availability and cost of reagents and energy for the process, and the impact of environmental regulations.

One promising system utilizes an ammonia-ammonium carbonate leach that recovers the nickel, copper and cobalt while leaving the iron and manganese in the tailings.[22] The technology for such a system is well documented in its application to nickel and copper oxide ores.[23]

The specific ammonia leaching system used in the baseline case of our deep ocean mining study model is based, in part, on a system described by engineers at Kennecott Copper's Ledgemont

Laboratory.[24] In this system, the nodules are first crushed to a diameter of 3/8 inch and are dried in a fluid bed dryer. They are then ground to a diameter of 50 microns and heated in a fluid bed furnace to reduce the metal oxides to pure metal. The reduced ore is then fed into a series of mixing vessels and thickeners that run counter to the flow of the leaching solution. Air is injected into the mixing vessels to oxidize the metals into soluble ammonia complexes. The pregnant leach liquor is then passed through a series of liquid ion exchange (LIX) columns to separate the nickel, copper, and cobalt and to send them to electrowinning tanks where the pure metals are recovered. The leach solution, stripped of metal values, is recycled and the tailings from the final thickener are sent to a steam stripping tower to recover ammonia and carbon dioxide. The data required to describe this system are shown in Table D-3. They comprise a list of the major items of processing equipment, factors that describe the capital cost of each item, and the specific energy and material consumption of each item. Also, the process is divided into major sub-groups to determine the labor requirements of the system.

The cost of installed equipment is estimated by a power law expression of the form:

$$\text{Cost} = \text{constant} \times [\text{processing rate}]^{\text{exponent}}$$

The processing rate is equal to the hourly rate of ore for equipment that processes ore (TYPE = 0) and to the hourly rate of recovered metal for equipment that processes metal (TYPE = 1). The definitions of the hourly rates of ore and metal are found earlier in this appendix. The values of the constants and exponents for each item of process equipment are tabulated in Table D-1.

Table D-1, Capital Cost Estimation Factors for Process Plant

	Constant	Exponent
Crushers (2 units in parallel)	170.23	1.22
Dryer	205800.0	.72
Grinders (2 units in parallel)	13602.0	.70
Reduction Furnace	339337.0	.72
Mixing Vessels with Agitators (7 units in series)	107362.0	.81
Pumps, Centrifugal (7 units in series)	9343.0	.34
Pumps, Diaphram (7 units in series)	4323.0	.50
Thickeners (7 units in series)	151798.0	.60
LIX Circuit	7568000.0	.60
Electrowinning	1208500.0	1.00
Stripping Tower	311331.0	.71

— — —

All costs are updated to first quarter 1976. The coefficients for the crushing and grinding operations and for the overflow and underflow pumps in the leaching circuit are taken from cost estimates by H. F. Mills[25] and K. M. Guthrie.[26] The costs for the drying and reduction steps are derived from data on the roasting equipment of the Cambishi RLE plant in Zambia,[27] and from the pilot operations at the Anaconda plant in Twin Buttes, Arizona.[28] The LIX circuit coefficients are based on a design and cost analysis performed by engineers at General Mills.[29] The electrowinning costs are from a study made at the Colorado School of Mines.[30] The cost of the stripping tower is estimated from approximate costs given by Kennecott's Ledgemont Laboratory.[31] The costs of mixing vessels and agitators are based on a 30 minute residence time in stainless steel vessels at each stage of the leach.[32] The costs are obtained from Happel and Jordan.[33] The size of the thickeners required in the plant is estimated from the results of the Twin Buttes pilot plant, which required up to 9.2 square feet of settling area for each ton per day of of the daily processing rate.[34] The cost of the thickeners is found in the Chemical Engineer's Handbook.[35] Cooling water requirements are taken from study of nodule processing systems conducted by EIC Corporation.[36]

B. Operating Requirements

The material requirements of the processing system can be estimated from the requirements of the individual items of processing equipment. This is achieved by determining the specific material requirements of the items of equipment from previous examples of metallurgical and chemical processing. The specific requirements are given in units of material or energy per ton of material processed. In particular, in the nodule processing operation four specific consumptions are considered: electric power, fuel, steam and chemicals. The requirements of each material are given in units per ton of ore processed, except for the LIX circuit and for the electrowinning system which are in units per ton of metal recovered.

Electric power in the grinding and crushing operations is determined by the equation:

$$\text{Power} = 10 \times B\ (1/P - 1/F)$$

where P is the product diameter, F is the feed diameter, and B is the Bond Index, which for nodules in 7 KW-HR/ton.[37] The power consumed by the fluid bed dryer is estimated at 8.95 KW-HR/ton and the roaster, which cycles the ore through its bed a second time, requires twice that amount.[38] The power required by the electrowinning equipment is 1.2 KW-HR pounds of metal recovered.[39] The power consumption in the LIX circuit is derived derived from the work of Merigold and Sudderth at General Mills.[40] The power requirements of the other equipment is based on the motor size used in each application. The electric power consumption for each operation is tabulated in Table D-2.

Table D-2, Schedule of Specific Consumption of Electric Power

(Power in KW-HR/Ton)

Operation	Material Being Processed	Specific Consumption
Crushing & Grinding	Ore	9.53
Dryer	Ore	8.95
Reduction Furnace	Ore	17.90
Agitators	Ore	6.26
Pumps	Ore	.47
Thickeners	Ore	.19
LIX Circuit	Metal	11.11
Electrowinning	Metal	2400.0
Stripping Tower	Ore	0.0

— — —

Fuel is consumed during the drying and reduction stages of the processing operation. The fuel may be supplied as a low BTU synthetic gas at the rate of 1.5 million BTU and 2.5 million BTU per ton of ore for the dryer and furnace, respectively.[41]

Steam is required for the stripping tower to remove the ammonia and carbon dioxide from the tailings slurry that leaves the thickeners prior to the disposal of the tailings. Steam is measured in units of pounds, and the specific requirement of the stripping tower is 1000 pounds per ton of ore.[42]

Because of the variety of chemicals that might be used in a processing operation, with a different price for each chemical, this model specifies the specific consumption of chemicals in units of $/ton of material processed. In this manner the cost of chemicals can be determined without the need to specify individually the prices of all chemicals in the process. The chemicals that are considered in this process are the make-up of ammonia that is lost during the operation and the replacement of chemicals used in the LIX circuit. Ammonia cost is estimated to be $1 per ton of ore,[43] and LIX chemicals, which include the organic medium, the ion exchange chemical, and acid for stripping the unwanted metals from the circuit, cost $13.47 per ton of metal recovered.[44]

Chilled water is required in the LIX section, the electrowinning section, and in the ammonia recovery section of the processing plant.[45] The chilled water requirement for each unit is specified by the variable CW(I) in gallons of chilled water per ton of material processed by the unit. The total chilled water requirement of the entire processing plant is used in the capital cost estimation section of the model to determine the investment in the central cooling tower of the utilities sub-sector.

C. Data Format

The first two items of data about the processing system, to be used in the deep ocean mining study model, are the number of items of processing equipment (NN) and the number of processing sub-groups (NSG). The number of sub-groups is used to estimate the total labor requirement of the processing plant. For the ammonia leaching plant, the number of sub-groups is 6: crushing and grinding, drying and reduction, leaching, LIX circuit, electrowinning, and tailings handling. The remaining data to be used in the program are the descriptions of the individual items of processing equipment. Each item is described by the type of metal processed [TYPE(I)], the constant [BASE(I)] and exponent [EXP(I)] that describe the capital cost of the equipment, and the specific consumption of power [P(I)], fuel [F(I)], steam [S(I)], and chemicals [CH(I)] and cooling water [CW(I)].

Table D-3, Processing System Data for the Deep Ocean Mining Study Model

Number of items of processing equipment: NN = 11

Number of processing sub-groups: NSG = 6

Unit	I	TYPE(I)	BASE(I)	EXP(I)	P(I)	F(I)	S(I)	CH(I)	CW(I)
Crusher	1	0	170.23	1.22	4.77	0.0	0.0	0.0	0.0
Dryer	2	0	205800.0	.72	8.95	1.5	0.0	0.0	0.0
Grinder	3	0	13602.0	.70	4.77	0.0	0.0	0.0	0.0
Furnace	4	0	339337.0	.72	17.9	2.5	0.0	0.0	0.0
Mixers	5	0	107362.0	.81	6.26	0.0	0.0	0.5	0.0
Pumps, Cent.	6	0	9343.0	.34	.23	0.0	0.0	0.0	0.0
Pumps, Diaph.	7	0	4323.0	.50	.23	0.0	0.0	0.0	0.0
Thickeners	8	0	151798.0	.6	.19	0.0	0.0	0.5	200.0
LIX Circuit	9	1	7568000.0	.6	11.11	0.0	0.0	13.47	5780.0
Electrowinning	10	1	1208500.0	1.0	2400.0	0.0	0.0	0.0	26600.0
Stripping Tower	11	0	311331.0	.71	0.0	0.0	1.0	0.0	4000.0

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Table D-4, Initial Values of Input Variables in the Processing Sector

Variable	Description	Value	Units
ARO	Annual Rate of Recovery of Ore	3000000	Dry Short Tons
ARST	Area of Processing Plant Site	200	Acres
BFAC	Buildings Cost Estimation Factor	.1	
COALPR	Price of Coal Delivered to Plant	15	$/Ton
CONFEE	Contingency Fee	.15	
DIS1	Distance from Port to Processing Plant	5	Miles
DIS2	Distance from Plant to Waste Disposal Area	25	Miles
DIS3	Distance from Plant to Rail Transportation	5	Miles
ENGFEE	Engineering Fee	.05	
FID	Construction Indirect Cost Factor	1.4	
KOPS	Length of Operating Life of Mining Project	25	Years
LAND1	Price of Land at Waste Disposal Site	2000	$/Acre
LAND2	Price of Land at Plant Site	10000	$/Acre
LAND3	Price of Land at Port Facility	20000	$/Acre
LAND4	Price of Land between Port and Plant	2000	$/Acre
LAND5	Price of Land along Waste Disposal Pipeline	1000	$/Acre
PAYOHD	Overhead on Operating Labor and Supervision	.25	
PINSRT	Insurance Rate on Processing Plant	.01	
PORTAR	Area of Port Facility	10	Acres
POWLIM	Upper Limit on Power Plant Capacity	25100	KW

Variable	Description	Value	Units
PP	Price of Commercial Electric Power	.03	Dollars
PPEFF	Power Plant Energy Conversion Efficiency	.33	
PRLNR	Price of Liner for Waste Tailings Ponds	2	$\$/yd^2$
PRPCST	Cost of Pre-Construction Land Preparation	4.39	$\$/yd^2$
RLCMP	Cost of Rail Facilities	234000	$/Mile
SCPM	Cost of Slurry Pipeline	250000	$/Mile
SGEXP	Cost Equation Exponent for Syn-Gas Plant	.8	
SHRCST	Cost of Shore-side Facilities at Port	664850	Dollars
SLRYOP	Operating Cost of Slurry Pipeline	.01	$/Ton-Mile
STMEFF	Energy Conversion Efficiency of Steam Plant	.9	
STXRT	State Tax Rate of Processing Sector	.01	
UPKF	Maintenance Cost Estimating Factor	.04	
WAGE	Operating Labor Wage	8	$/Hour
WD	Work Day of Processing Sector	24	Hours
WRFCST	Cost of Wharf Facility	1250000	Dollars
WY	Work Year of Processing Sector	300	Days
YRDCST	Cost of Yard Improvements at Plant	558600	Dollars

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Utilities Sub-Sector is composed of six modules: Synthetic Gas Generation, Power Production, Steam Generation, Chilled Water Supply, Power Distribution, and Steam Distribution. Refer to specific module specification sheets for further details.

COST FORMULA: UCC = SGCST + PPCST + BLRCST + CTCST + PDCST + SDCST

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Steam generation

COMPONENT: N/A

DESCRIPTION: Steam generating boiler and all installation materials; F D fans, instruments, controls, burners, soot blowers, etc.; Feed water deareator, chemical injection system, structural steel & platforms, stack, field erection, sub-contractor indirects and contractor installation.

COST FORMULA: $BLRCST = 4870000 \times (STM/520)^{.8}$

REFERENCE: Chemical Engineering, March 24, 1969.
Updated to 1st quarter 1976 cost by M & S index ratio of 1.69

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Steam distribution

COMPONENT: N/A

DESCRIPTION: Distribution of steam throughout plant for general use.

COST FORMULA: SDCST = STM x 2570

REFERENCE: Chemical Engineering, March 24, 1969, page 136. Cost updated to 1st quarter 1976 by M&S cost index ration of 1.69.

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Power Plant

COMPONENT: N/A

DESCRIPTION: Complete power plant, including steam generator, turbo-generating facilities, foundations, field erection subcontractor indirects.

COST FORMULA: $PPCST = 13750000 \times (PPR/25100)^{.75}$

REFERENCE: Chemical Engineering, 24 March, 1969, page 139. Cost updated to 1st quarter 1976 by M & S index ratio of 1.69.

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Power distribution

COMPONENT: N/A

DESCRIPTION: Distribution facilities and wiring for entire plant demand of electricity.

COST FORMULA: PDCST = POWR x 158

REFERENCE: Chemical Engineering, 24 March, 1969, page 136. Cost updated to 1st quarter 1976 by M & S index ratio of 1.69.

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Cooling tower

COMPONENT: N/A

DESCRIPTION: Cooling tower, utilizing a 15° F temperature drop, based on actual construction operating at 37,000 GPM, and scaled by power law formula. Concrete basin, pumps and drivers, field erection and sub-contractor indirects.

COST FORMULA: $CTCST = 687000 \times [CWR/(37000 \times 60)]^{.6}$

REFERENCE: Hydrocarbon Processing, December, 1976 (Offsites Issue).
Exponent for cost equation from Chemical Engineering, 24 March, 1969, page 139.

SECTOR: Processing

SUB-SECTOR: Utilities

MODULE: Synthetic gas plant

COMPONENT: N/A

DESCRIPTION: Low BTU coal gasification plant including coal preparation, dust removal, waste heat recovery, sulfur recovery plant, and waste treatment plant.

COST FORMULA: $SGCST = 88600000 \times (SGAS/9000)^{SGEXP}$

REFERENCE: Katell & White, "Economic Comparison of Synthetic Fuels," in AACE Transactions 1976, page 104. Also, discussion with Kenneth Plants, USBM Process Evaluation Group, Morgantown, W.Va.

NOTE: The costs reported in Katell & White are capital cost of the entire plant, ready for operation. In order to calculate the direct cost of construction from this figure Mr. Plants recommended the following relationships:

1) Reported Cost = Direct Cost + Indirects + Eng. & Overhead + contingency + Contractor Fee.
2) Indirects = 1/8 of Direct Cost;
3) Eng. & Ovhd = 15% of Direct + Indirect Costs
4) Contingency = 20% of Direct, Indirect, Eng. & Ovhd.
5) Contractor Fee = 7.5% of all other costs.

SECTOR: Processing

SUB-SECTOR: Buildings

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: All building used in the processing sector, not including structure associated with portions of the utilities sub-sector.

COST FORMULA: BLCC = BFAC x EC

REFERENCE: Chemical Process Economics, page 241. For the baseline model the cost of buildings is assumed to be near the low range recommended by this reference because the site location is assumed to be Southern California, where a minimum of weather protection is necessary. Alternate locations may increase this cost.

SECTOR: Processing

SUB-SECTOR: Site Development

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Site development sub-sector is composed of the cost of the port facility, the cost of transport systems, the cost of land purchase and preparation, and the cost of yard development and construction.

COST FORMULA: SCC = PRTCST + PLTCST; where
PLTCST = LNDCST + TRNCST + YRDCST

REFERENCE: See site development specification sheets of various cost modules for further information.

SECTOR: Processing

SUB-SECTOR: Site Development

MODULE: Development

COMPONENT: N/A

DESCRIPTION: Module is comprised of cists of yard improvements and construction of nodule and coal storage areas.

COST FORMULA: DEVCST = YRDCST + STRCST

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Development

COMPONENT: Yard improvements

DESCRIPTION: Well (1200 gpm) $52,000; Sewer (2000 ft) $51,000 Fire House $254,000; Fencing (12000 ft) $50,400; Lighting $88,000; Drinking Water $9,100; Fire Loop $38,000; Parking (300 cars, 21 yd^2: $9,800; Main access Road (6 x 1000 yd): $6,300

COST FORMULA: YRDCST = 558,600

REFERENCE: Well and Sewer costs from Mills, Chemical Engineering, 19 March, 1964. Costs updated to 1st quarter 1976 by M & S index ration of 1.8. Other costs from Guthrie, Chemical Engineering, 24 March, 1969, page 136. Costs updated to 1st quarter 1976 by M & S index ration of 1.69.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Development

COMPONENT: Storage facilities

DESCRIPTION: Nodules: asphalt lines storage area- 45' height of nodules with average excavation of 7 yd. Excavation at $\$2.74/yd^3$; Asphalt at $\$10.50/yd^2$. Estimated 1976 cost for 1 month storage is .126 x ARO. Coal: one month supply, 20' high, area = .017 x ARO (results in square feet). Surface at $\$10.50/yd^2$; cost = .02 x ARO

COST FORMULA: STRCST = ARO x (.126 + .02)

REFERENCE: Chemical Engineering, March 24, 1969, page 136. Costs updated to 1st quarter 1976 by M & S index ration of 1.69.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Land

COMPONENT: N/A

DESCRIPTION: Purchase and preparation of land for processing plant. Clearing, leveling, and grading at $\$1.52/yd^2$. Landscaping at $\$2.87/yd^2$. Total preparation cost at $\$4.39/yd^2$. 5000 yd^2 per acre. Area of site represented by variable ARST, initially 200 acres.

COST FORMULA: LNDCST = LAND2 x ARST + PRPCST x ARST x 5000

REFERENCE: Site Area from Dames & Moore/EIC report. Costs are from Chemical Engineering, 24 March, 1969, and are updated to 1st quarter 1976 by M & S cost index ration of 1.69

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Transport

COMPONENT: N/A

DESCRIPTION: Rail access to plant and slurry pipeline to port facility. Includes purchase of land along pipeline right-of-way, at 6 acres per mile.

COST FORMULA: TRNCST = RLCPM x DIS3 + SCPM x DIS1 + DIS1 x 6 x LAND4

REFERENCE: Further information provided in specification sheets for transport components of Railway and Slurry Pipeline.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Transport

COMPONENT: Railway

DESCRIPTION: Railway line including track, ballast, and grading of right-of-way. \$44.4/ft. (1976 cost)

COST FORMULA: RLCPM = 234,000

REFERENCE: Chemical Engineering, 24 March, 1969. Costs updated by M & S index ratio of 1.69.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Transport

COMPONENT: Slurry pipeline construction

DESCRIPTION: 8" dia. transport line, 4" return line. Grading at $1.52/yd^2, landscaping at $2.87/yd^2, excavation of 4.5' x 4' trench at $1.91/linial foot. Pipe cost: 8" sch. 80 at $13.50/ft.; 4" sch. 80 at $5.10/ft. (including labor at $10/hour), welds every 30 feet at $45 each for 8", and $22 each for 4" (computed at $10/yr).

COST FORMULA: SCPM = 272,210

REFERENCE: Dames & Moore report, Chapter 3.
Pipe and welding costs from Mills, Chemical Engineering, 19 March, 1964. M & S index ratio = 1.8.
Other costs from Guthrie, Chemical Engineering, 24 March, 1969, M & S ratio = 1.69.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Port cost

COMPONENT: N/A

DESCRIPTION: Receiving station for nodules. Pier facility is provided for unloading (the cost of transfer pumps and piping is accounted for in the transport sector). Buffer storage is provided for the rapid unloading of nodules until they can be transferred to the plant by pipeline. Also, land on coast for site.

COST FORMULA: PRTCST = WRFCST + SHRCST + PORTAR x LAND3

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Port facility

COMPONENT: Pier

DESCRIPTION: Concrete wharf, 1968 cost at $21.25/ft^2; 1976 at 36/ft^2. Dimension: 400 ft by 30 ft: $432,000. Dredging of Access Channel 600 ft. x 20 ft. x 100 ft., 1968 at $11/yd^3: $820000.

COST FORMULA: WRFCST = 1,250,000

REFERENCE: Chemical Engineering, 24 March, 1969, page 136. Costs updated by M & S cost index ration of 1.69.

SECTOR: Processing

SUB-SECTOR: Site development

MODULE: Port facility

COMPONENT: Shore development

DESCRIPTION: 1.8 acre settling pond. Grading of 10 acre site at $1.68/yd^2$, landscaping at $\$2.88/yd^2$, pond excavation at $\$2.54/yd^3$, lining at $\$10.50/yd^2$, fencing at $3.60/ft (630' per side), 5000KVA transformer station at $39/KVA, parking for 30 cars at $\$10.50/yd^2$ ($21\ yd^2$/car + 50% maneuvering space), yard lighting at $31750.

COST FORMULA: SHRCST = 664,850

REFERENCE: Dames & Moore Study provided acreage.
Costs from Chemical Engineering, 24, March, 1969.
Costs updated by M & S cost index ratio of 1.69.

SECTOR: Processing

SUB-SECTOR: Waste disposal

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Waste Disposal sub-sector capital cost is comprised of the cost of the land for the disposal of waste, the cost of the slurry pipeline that connects the plant with the disposal site, and the cost of the land on the pipeline right-of-way. Costs are divided between land costs and pipeline costs.

COST FORMULA: WCC = WLDCST + WSLCST

SECTOR: Processing

SUB-SECTOR: Waste disposal

MODULE: Pipeline

COMPONENT: N/A

DESCRIPTION: The cost of the slurry pipeline is based on the calculation of pipeline construction cost found in the site development sub-sector transport module specification sheet.

COST FORMULA: WSLCST = SCPM x DIS2

REFERENCE: See Site Development Sub-Sector, Transport Module, Pipeline Component Specification Sheet.

SECTOR: Processing

SUB-SECTOR: Waste disposal

MODULE: Land purchase

COMPONENT: N/A

DESCRIPTION: Land for the pipeline right-of-way requires 6 acres per mile of pipeline. Land for the disposal site is required at a rate of 100 acres per year for a 3 million tons per year operation. All land is purchased during investment period. Improvements to the land and preparations for wast disposal are considered to be operating costs.

COST FORMULA: WLDCST = LAND1 x KOPS x ARO/30000 + DIS2 x 6 x LAND5

REFERENCE: Dames & Moore Waste Disposal Study provided estimates about land requirements.

SECTOR: Processing

SUB-SECTOR: Equipment

MODULE: N/A

COMPONENT: N/A

DESCRIPTION: Processing equipment includes value of all individual costs of processing equipment units specified by variable COST(I).

COST FORMULA: $EC = \sum_{I=1}^{NN} COST(I)$

Appendix D Notes

1. Kenneth M. Guthrie, "Capital Cost Estimating," Chemical Engineering, March 24, 1969, p. 114.

2. Ibid., p. 117.

3. Ibid.

4. John Happel and Donald Jordan, Chemical Process Economics, New York, 1975, p. 241.

5. Dames & Moore and Benjamin V. Andrews, Draft Report -- Description of Transportation and Waste Disposal Systems for Manganese Nodule Processing, March 16, 1977, p. 4.0-10.

6. Ibid., p. 5.0-14.

7. Sidney Katell and L.G. White, "Economic Comparison of Synthetic Fuels -- Gasification and Liquification," in Transactions of the American Association of Cost Engineers, 1976, p. 104

8. Mechanical Engineer's Handbook.

9. ASME Steam Tables.

10. The labor requirement for a 250 MM SCF low BTU gasification plant is taken from Katell and White, p. 106. The requirement is scaled to smaller plants by an exponent of .25, suggested by Happel and JOrdan, p. 248.

11. Theodore Balberyszski and A.K. Anderson, "The Economics and Optimization of Copper Electrowinning at High Current Densities," in Electrometallurgy, p. 196.

12. Happel and Jordan, p. 248.

13. Harold J. Bennett, et al, "An Economic Appraisal of the Supply of Copper from Primary Domestic Sources," BuMines Information Circular 8598, p. 146.

14. Ibid.

15. Ibid.

16. Happel and Jordan, p. 248. Also private industry sources.

17. Ibid., p. 251.

18. Bennett, p. 146.

19. Dames and Moore, p. 5.0-14.

20. Agarwal, *passim*.

21. *Ibid*. See also Paul Cardwell, "Extractive Metallurgy of Ocean Nodules," *Mining Congress Journal*, November, 1973, pp. 38-43.

22. Agarwal, "Processing," p. 13. See also K.N. Han *et al*, "Ammonia-Ammonium Leaching of Deep-Sea Managanese Nodules," *International Journal of Mineral Processing*, 1 (1974), pp. 215-230.

23. L.R. Verney *et al*, "Development and Operation of the Cambishi Process for the Roasting, Leaching and Electrowinning of Copper," in *Electrometallurgy*, ed. Henrie, Baker, New York, 1969, pp. 273-302. Also , C.R. Merigold and R.B. Sudderth, "Recovery of Nickel by Liquid Ion Exchange Technology," in *2nd International Symposium on Hydrometallurgy*, pp. 552-588.

24. Agarwal, "Processing," pp. 8-9. The intermediate and final grid sizes are suggested by R.F. Frantz and T.P. McNulty in "Leaching of Copper Silicate Ore with Aqueous Ammonium Carbonate," in *2nd International Symposium on Hydrometallurgy*, Baltimore, 1972, pp. 627-643.

25. H.E.Mills, "Costs of Process Equipment," *Chemical Engineering*, March 16, 1964, pp. 134-135 and p. 137.

26. K.M. Guthrie, "Capital Cost Estimating," *Chemical Engineering*, March 24, 1969, p. 132

27. L.R. Verney *et al*, pp. 273-302.

28. Frantz and McNulty, pp. 627-643.

29. Merigold and Sudderth, pp. 552-588.

30. Theodore Balberyszski and A.K. Anderson, "The Economics and Optimization of Copper Electrowinning at High Current Densities," in *Electrometallurgy*, pp. 185-205.

31. Agarwal *et al*, "Processing," pp. 13-14.

32. Frantz, p. 637, uses a 1 hour residence time and two leaching tanks. The model system has 7 leaching stages so the residence time is reduced.

33. Happel and Jordan, pp. 229-230.

34. Frantz, p. 641.

35. Perry and Chilton, eds., Chemical Engineer's Handbook, 5th Edition, New York, 1973, p. 19-56.

36. Dames & Moore and E.I.C. Corp., Progress Report -- Description of Manganese Processing Systems for Environmental Studies, Volume II, p. A26.

37. Agarwal, "Processing," p. 2.

38. Verney, p. 284.

39. Balberyszski, p. 109.

40. Merigold and Sudderth, p. 581 and p. 583.

41. Agarwal, "Processing," p. 12.

42. Agarwal, "Processing," p. 13.

43. Ibid., p. 12. See also R.F. Frantz and T.P. McNulty, "Leaching of Copper Silicate Ore with Aqueous Ammonium Carbonate," 2nd International Symposium on Hydrometallurgy, ed. Evans and Shoemaker, (Baltimore, 1972).

44. Merigold and Sudderth, p. 581.

45. Dames & Moore andEIC Corp., Progress Report, p. A26.

APPENDIX E, Financial Analysis

I. Introduction

As noted in Chapter III, the financial analysis section integrates the various chronological, technological, economic, financial and policy factors that enable the model to define the typical conditions under which a first generation ocean mining project might function and to estimate the returns to both the private and the public sectors.

To permit the public decision-maker to evaluate the effect of any given set of changes to the baseline conditions, the model must be flexible. Within the financial analysis section, flexibility is provided to evaluate the sensitivity of the project to changes in discrete factors or combinations of factors.

It is the purpose of this appendix to provide greater detail regarding the assumptions and methodology underlying the financial analysis section and, in particular, to relate the previous description of the section (Chapter III-E) to the computer algorithm.

Component description. In addition to the major components of the section described in Chapter III, the financial section contains the mechanisms for executing the model and for performing various sensitivity analyses. The remainder of this appendix will follow the outline of Chapter III-E and address project scheduling, annual net cash flow determination and economic return calculation. This last description will also detail the calculations used to estimate the income to the public sector and the benefits to the nation as a whole.

1. Sensitivity Analyses and Cost Aggregation

The financial analysis section has been developed to allow the cost inputs used to describe the technology of a minerals recovery operation such as ocean mining to be accepted at any level of disaggregation.[1] Following the IRS guidelines recommended to account for depreciable property, the section uses multiple asset accounts, grouped according to use and classified into sections according to the Class Life Asset Depreciation Range (ADR) System.[2] Defining the capital cost components [CAPCST] in this manner gives the model the capability to accept cost specification at any level desired, using as many group and sector designations as necessary. Six asset groupings within each of five sectors are permitted in the current version of the model. As described in earlier appendices, for this study, only three sectors -- mining, transport, and processing -- are used, each sector having no more than five groups.

Similarly, the operating costs [OPCST] associated with the three sectors use five discrete groupings.

The first operation of the model is to set these cost arrays to zero which is done by the following series of equations:

```
      DO  160      S1=1,NS
          SCPCST(S1)=0.0
          SOPCST(S1)=0.0
      DO  160      G1=1,NG
          CAPCST(S1,G1)=0.0
          OPCST(S1,G1)=0.0
  160     ADP  (S1,G1)=0.0
```

The cumulative sector capital costs [SCPCST], sector operating costs [SOPCST] and each grouping's accumulated depreciation account [ADP] are also initialized the respective sector [S1] and group [G1] indices are used to control this operation.

Following initial setting of these arrays, the cost estimation section assigns the designated asset costs and their associated annual operating costs. If evaluation of other mineral recovery technologies is desired, the level of cost specification is chosen, the arrays are given appropriate dimension and the number of sectors [NS] and groups [NG], are redefined. The costs are then entered using the namelist PROJKT (explained in Appendix G) and the sector cost estimation routines described in earlier appendices are bypassed using the equations:

```
    IF (MTO.EQ.1)  GO TO 250
250 IF (MPO.EQ.1)  GO TO 260
260 CONTINUE
```

After the various costs have been assigned, they are multiplied by the sensitivity factors for capital costs [CCSF] and operating costs [OCSF] and aggregated into representative sector costs which, in turn, are further collected to provide the total capital costs [TCAC] and total operating costs [LOC] associated with the project. The operating costs anticipated during the intra-operational delay period [DOC] are similarly collected. The series of equations which accomplish this are:

```
    TCAC = 1.1
    LOC = 0.0
    DOC = 0.0
    DO 1 S1 = 1,NS
    DO 1 G1 = 1,NG
       FCPCST(S1,G1) = CAPCST(S1,G1) * CCSF(S1,G1)
  1    FOPCST(S1,G1) = OPCST(S1,G1)  * OCSF(S1,G1)
    NG1 = NG-1
    DO 3 S1 = 1,NS
    DO 2 G1 = 1,NG
                  SCPCST(S1) = SCPCST(S1,G1) + FCPCST(S1,G1)
                  SOPCST(S1) = SOPCST(S1,G1) + FOPCST(S1,G1)
  2 TCAC = TCAC + SCPCST(S1)
    LOC = LOC + SOPCST(S1)
  3 DOC = DOC + OPCST (S1,NG)
```

Market prices of the recovered elements [MV(J)] can also be varied to evaluate the sensitivity of the project to changes in their values. Using the following equations:

```
   DO 4 J = 1,NOM
 4 FMV(J) = MV(J) * MVSF(J)
```

the sensitized market values [FMV(J)] for each of the total number of elements recovered [NOM] are computed.

Finally, the nominal annual production level [LNAP], expressed in millions of dry short tons of nodules, is found by dividing the annual rate of ore production [ARO] by one million:

```
LNAP = ARO/1000000,
```

Following definition of the various endogenous variables used in the program, the next operation of the financial analysis section is to schedule the project.

2. Project Scheduling

Definition of the project timelines is the key to the financial analysis, as this function phases the various expenditures over the life of the project. As noted earlier, four major periods are used to define project life. The first three are:

-- the pre-investment period [KRD];

-- the investment period [KINVST]; and,

-- the production period [KOPS].

The fourth period, the total delays period [KDLY], represents the sum of all anticipated delays [DLY(Y)] which might occur during the project. In order to incorporate delay scheduling into the model, five arbitrarily selected delay periods have been created for illustrative purposes:

DLY(1) = Pre-Research and Development Delay;
DLY(2) = Pre-Investment Delay;
DLY(3) = Intra-Investment Delay;
DLY(4) = Pre-Operation Delay; and,
DLY(5) = Intra-Operation Delay

The sum of these periods denotes the total delay in the project:

```
      DO 10 Y = 1,5
   10 KDLY = KDLY + DLY (Y)
```

The lifetime of the project [KLIFE] is then the sum of the major periods:

KLIFE = KRD + KINVST + KOPS + KDLY

Key times in the life of the operation have been denoted through the use of the three periods and the various delays. The beginning of both the research and development period [KRD] and the prospecting period [KPP] follows the initial delay period, pre-R&D delay, denoted by KO:

KO = DLY(1)

Investment starts after the conclusion of any interim delay following R&D activity, denoted by K2:

K2 = K1 + DLY(2)

Prospecting may continue, however, and does not end until K = K16:

K16 = KO + KPP

The major minesite exploration period [KPE] commences with the start of investment and concludes when K = K14:

K14 = K2 + KPE

while the investment period ends when K = K5:

K5 = K4 + KV2

Following any interim delay, ending when K = K6:

K61 + K6 + 1

Other important times include the operation startup period [KSU], ending when K = K12:

K12 = K6 + KSU,

the amortization period [KLN], ending when K = K10:

```
K10 = K5 + KLN,
```

and the depreciation period [KDPMAX], ending when K = K9:

```
K9 = K6 + KDPMAX
```

All time designators, including the key times discussed above, are summarized on the annotated project time line, diagrammed in Figure E1. The relative time line of the model project initiation [YEAR1]:

```
   YEAR(1) = YEAR1
   KL = KLIFE-1
   DO 20 K = 1, KL
20 YEAR(K+1) = YEAR1+K
```

3. Annual Net Cash Flow Estimation

a. Gross Revenues

The first step in determining annual net cash flow is to compute the annual revenues generated by the project through sale of recovered minerals. To do so, the production of nodules in any year must be defined. If normal operations exist, annual production [NAP] will be equal to the nominal annual production level. If the operation period has not been reached, or if attained, interrupted by delay, annual production is zero. During startup, when the operation is not functioning at design efficiencies, annual production will fall short of the nominal. These determinations are made by the following series of equations:

```
NAP = LNAP
IF (K.LE.K6OR.K.GT.K7.AND.K.LE.K8) NAP = 0.
IF (K.GT.K6.AND.K.LE.K12) NAP = NAP * SREF(C1)
```

The total annual gross revenues [GR(K)] are determined by summing the annual revenues from each metal [GRM(J,K)], computed by multiplying the annual production yield of each metal [QUAN(J,K)] in pounds, by its market price [FMV(J)], expressed

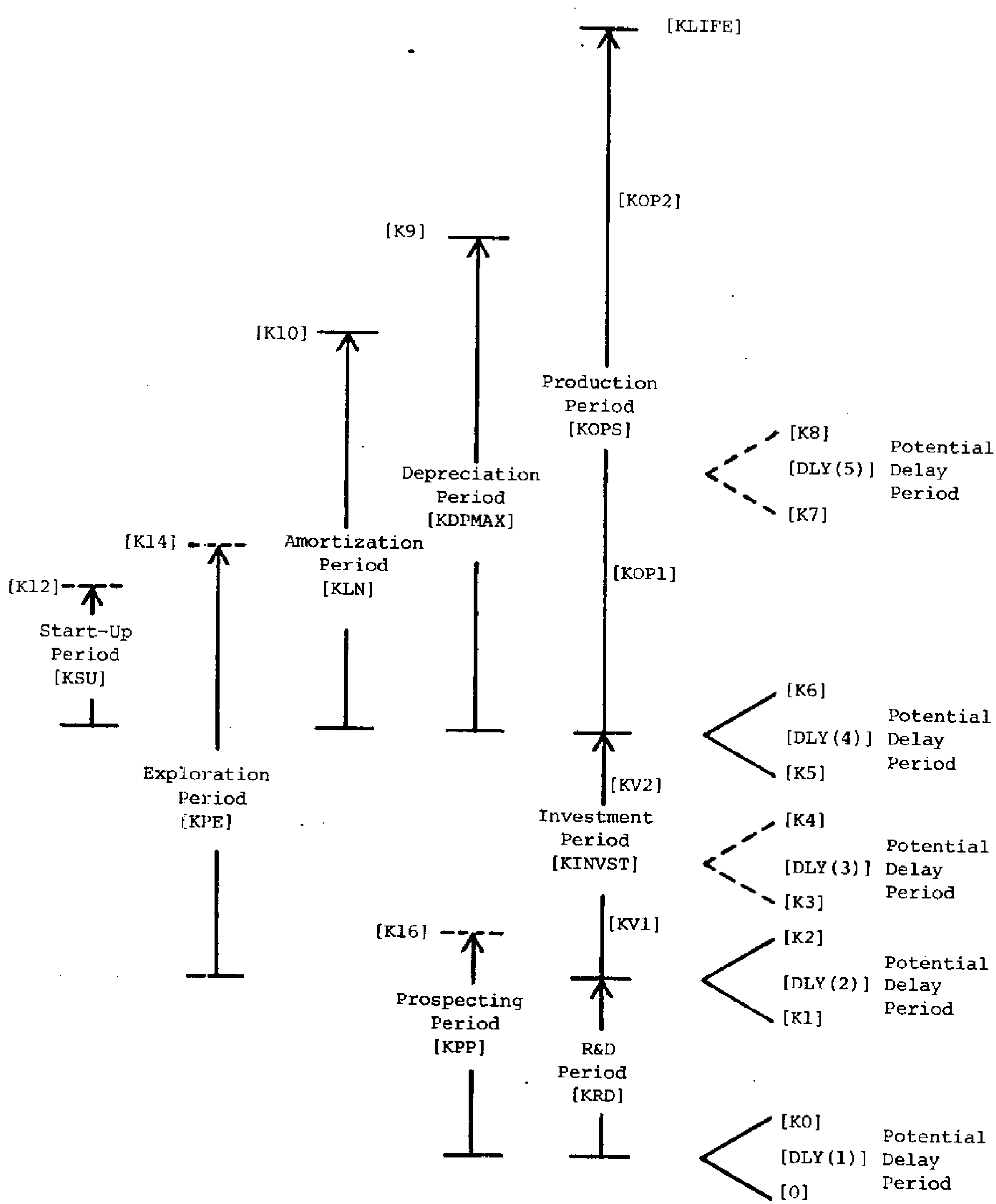

Figure E1

Annotated Project Timeline

in dollars per pound. The following equations accomplish this:

```
      DO 55 J = 1,NOM
      QUAN(J,K) = 0.2 * NAP * COMP(J) * RE(J)
      GRM(J,K)) = QUAN(J,K) * FMV(J) * INF(K,2)
   55 GR(K) = GR(K) + GRM(J,K)
```

The value of the constant in the second equation (0.2) is a conversion factor from tons of ore to pounds of metal and considers the percent values of COMP(J) and RE(J). INF(K,2) is the metal price inflator.

Escalation. As noted earlier, the model has provision for analyses using either constant purchasing power (unescalated) dollars or current money (escalated) dollars. If the latter feature is desired, discrete annual escalation indices are used to convert the constant dollars normally specified. INF(K,T) is the annual index for capital investment, T equals 1; for revenues, 2; for expenses, 3; and, for the discount factor, 4. The latter is adjusted to preserve the "true discount rate employed.[3] The index for each category is computed by the following equations:

```
      DO 40 T=1, 4
   40 IF(K.LT.KLIFE) INF(K+1,T) = INF(K,T) * (1.+XIF (K+1,T)/100.)
```

XIF(K,T) is the operator designated percentage rate of change in each discrete annual index. All indices are, naturally, equal to unity in the first year of project initiation.

b. Annual Capital Investment

The annual capital investment [CAC(K)] is that portion of the total required project capital which is expended during each year of the investment project. The magnitude of any one year's expenditure is determined by the capital allocation factor [CAPFC(C3)], defined by the model's operator, with due consideration for the length of the investment period. This calculation is performed by the following equation:

```
      CAC(K) = TCAC * CAPFC (C3) * INF(K,1)
```

The percentage of eligible investment to be considered for investment credit is applied when the annual investment is calculated. However, non-qualifying assets' costs [XMPCST(K)] are removed first, as shown in the following equations:

```
EXCST(K) = XMPCST(K) * CAPFC(C3) *INF(K,1)
XCAC(K) = (CAC(K) - EXCST(K)) * XCT
IF(YEAR(K).LE.KTIC) XCAC(K) = (CAC(K)-EXCST(K)) * XTCT
```

The last equation substitutes the temporary ten percent credit [XTCT] if the investment year is prior to 1981 [KTIC].

c. Total Costs

Total costs [TC(K)] include the annual operating costs [OC(K)], the marketing and general expenses [MG(K)] and the annual outlays for prospecting, exploration and research and development [MES(K)].

As with gross revenues, annual operating costs are determined by the status of the project. If normal operations exist, these costs equal the total operating costs [LOC] computed in the cost estimation section of the model. Prior to commencement of operations, the annual operating costs are zero. During operational delay, annual expenses associated with certain fixed costs and equipment upkeep are included. During startup, yearly operating costs will vary from the planned level to reflect the extra cost burden of "debugging" the new technologies;[4] this is accounted for through the startup cost efficiency factor [SCEF(C4)]. To provide working capital for operations [OWC], the first production year's annual operating costs are increased by an operator defined percentage [WC] of the total operating costs; this working capital is recovered in the final production year. This entire sequence is summarized by the series of equations which follow:

```
OC(K) = LOC
OWC = WC * LOC
IF(K.LE.K6) OC(K) = 0.0
IF(K.GE.K61.AND.K.LE.K12)OC(K)=OC(K)*SCEF(C4)
```

```
IF(K.EQ.K61) OC(K)=OC(K) + OWC
IF(K.GT.K7.AND.K.LE.K8) OC(K) = DOC
IF(K.EQ.KLIFE) OC(K) = (1. - WC) *LOC
OC(K) = OC(K) * INF(K,3)
```

As with revenues and investments, the operating costs can be inflated using INF(K,3).

Marketing and general expenses directly attributable to the project are incurred annually with commencement of operations and are assumed to equal three percent of annual gross revenues. This is given by the following equation:

```
MG(K) = 0.03 * GR(K)
```

Prior to the production of saleable product, the marketing expenses associated with the project are assumed to be zero, although, in reality, there will be some marginal increase in the marketing expenditures of the various consortia members as long-term supply contracts are established.

As mentioned in Chapter III, the various total expenditures associated with prospecting [PRCS], exploration [EXPX] and research and development (RDX] are either specified by the model's operator and converted to appropriate units (as with prospecting and R&D) or computed by the model based upon required minesite size (as with exploration). These expenditures are converted to annual expenses by allocating each over the respective activity period, as done by the following equations:[5]

```
IF(MORTZ.EQ.O.AND.K.GT.K0.AND.K.LE.K15) MES(K)=RDX/FLOAT(KRD)
IF(K.GT.K0.AND.K.LE.K16) MES(K)=PRCS/FLOAT(KPP)+MES(K)
IF(MORTZ.EQ.O.AND.K.GT.KE.AND.K.LE.K14) XCST(K)=EXPX/FLOAT(KPE)
MES(K) =  MES(K) + XCST(K)
```

The annual expenses for R&D, prospecting and exploration are charged as miscellaneous expenses [MES(K)] to facilitate program accounting.

These various costs are then summed to define the total project costs as shown:

```
TC(K) = OC(K) + MG(K) + MES(K) * INF(K,3)
```

d. Federal Income Tax

The starting point for the determination of the annual tax payment is gross profit [GP(K)], defined as gross revenues less total costs:

```
GP(K) = GR(K) - TC(K)
```

i. Depreciation. Annual depreciation expense for each asset group is calculated by a subroutine [RECVRY]. Depending upon the method specified, depreciation will be calculated by one of the following IRS recommended procedures:

-- straight-line;

-- declining balance; or,

-- sum of the year's-digits.

To calculate depreciation, the subroutine requires as inputs the current year [K] and the depreciable life [KDP], the previous use designator [NU], the first cost [FCPCST], the salvage value percentage [SVP], the depreciation method [METH] and the accumulated depreciation account [ADP] of each asset group. This information is passed to the subroutine by the program statement:

```
      CALL RECVRY (K,KDP(S1,G1), NU(S1,G1),FCPCST(S1,G1),
     C        SVP(S1,G1)METH(S1,G1),ADP(S1,G1),DPG(S1,G1))
```

The annual depreciation expense for each asset group [DPG] is returned along with the group's updated accumulated depreciation account.

The various group depreciation accounts are summed, first for each sector [DPS], and then, for all sectors, to derive the annual project depreciation expense [DP(K)]. This is done by the following equations:

```
DPS(S1) = DPS(S1) + DPG(S1,G1)
DP(K) = DP(K) + DPS(S1)
XTDP = XTDP + DP(K)
TDP(K) = XTDP
```

The last pair of equations calculate the total accumulated depreciation [TDP(K)] for the project.

The subroutine calculates the salvage value [SVAL] and the annual adjusted cost [RCST] (i.e., first cost less salvage value less accumulated depreciation) for each asset group.

Straight-Line Depreciation. This method is specified by setting METH equal to 3. Under this method, depreciation expense is calculated by dividing the adjusted asset cost by the remaining useful life:[6]

```
DP = RCST/FLOAT(K6+KDP-K+1)
```

Declining Balance Method. This method is specified by setting METH equal to 4.

Under this method, the asset's first cost is adjusted annually by subtracting the accumulated depreciation and applying a rate [DBF/FLOAT(KDP)] up to twice the straight line rate to the remainder, depending upon certain asset characteristics.[7] This is done by the following equations:

```
RCST=COST-ADP
DP=RCST*DBF/FLOAT(KDP)
```

Usually, circumstances permit the use of twice the straight line rate and this is accomplished with the declining balance factor [DBF] equal to 2. If the asset is used or real property acquired after July 24, 1969, with a remaining useful life of at least three years, the maximum allowable rate is one and one half times the straight line rate. The model recognizes these qualifications with the previous use designator [NU]. When equal to 1, the asset group is so qualified and the factor redefined to equal 1.5. The asset may not be depreciated below its salvage value under any rate and the restriction is operative in the program.

Conversion to Straight-Line. The IRS allows taxpayers to convert from declining balance to straight-line depreciation at any time they desire. As the IRS does not require prior consent, this is usually done when the straight line method allows a greater annual depreciation expense, which produces higher annual cash flow. In the model, this method is specified by setting METH equal to 2. This is the method which has been used in this study and would be the method used by the program unless otherwise specified.

If conversion is desired, the annual depreciation expense calculated by the declining balance method [DP] is compared with the annual depreciation expense for the remaining cost [REMCST] if it were equally distributed over the remainder of the assets' useful life [KDPS]. When the latter computation produces an annual expense [DPSL] equal to or greater than the declining balance expense, the method converts to straight line for the balance of the assets' life. These computations are handled by the following series of equations:

```
      DPSL=(RCST-SVAL)/FLOAT(K6+KDP-K+1)
      IF(DPSL . GE.DP) METH=5
      IF(DPSL . GE . DP) REMCST(C2) = RCST-SVAL
      IF(DPSL. GE. DP) KDPS(C2) = K6+KDP-K+1
      IF(DPSL. GE. DP) ADP = ADP-DP
   30 IF (METH.EQ.5) DP=REMCST(C2)/KDPS(C2)
      IF (METH.EQ.5) ADP=ADP+DP
```

A subroutine index [C2] is assigned to permit discrete conversions by each asset group. The baseline depreciation schedule is presented, by sector for each year in Table E1.

<u>Sum-of-Years' Digits.</u> Under the IRS's remaining life plan, this method applies changing fractions to the unrecovered, or adjusted, cost of the asset reduced by estimated salvage value. The denominator of the fraction changes each year to a number equal to the total of the digits representing the estimated remaining useful life; the numerator also changes and represents the years of useful life remaining at the beginning of the current year.[8] In the subroutine, this method is chosen by specifying METH equal to 1 and the calculation of annual

TABLE E1.

Baseline Depreciation Schedule

Double Declining Balance/Straight-Line Conversion

($ 1976 X 1 Million)

Year	Mining Sector	Transportation Sector	Processing Sector	Annual Expense
1981	19.15	6.12	48.19	73.46
1982	15.32	5.44	41.39	62.13
1983	12.25	4.83	35.52	52.60
1984	9.82	4.30	30.51	44.63
1985	7.85	3.81	26.21	37.87
1986	6.28	3.39	22.57	32.24
1987	6.28	3.02	19.51	28.81
1988	6.28	2.68	16.91	25.87
1989	6.28	2.39	16.91	25.58
1990	6.28	2.12	16.91	25.31
1991	-	2.12	16.91	19.03
1992	-	2.12	16.91	19.03
1993	-	2.12	16.91	19.03
1994	-	2.12	16.91	19.03
1995	-	2.12	-	2.12
1996	-	2.12	-	2.12
1997	-	2.12	-	2.12
1998	-	2.12	-	2.12
Totals	95.79	55.06	342.25	493.10

depreciation expense is made by the following equation:

```
DP = RCST * FLOAT(2)/FLOAT(K6+KDP-K+2)
```

Subtraction of the annual depreciation expense from gross profit yields the annual income before interest and tax [EBIT(K)], as follows:

```
EBIT(K) = GP(K) - DP(K)
```

ii. Interest and Debt Financing. As noted in Chapter III-E, debt financing is available through intermediate term loans. These loans usually carry restrictive covenants and the model provides two: 1) a limit on the account of cash flow available to service debt; and 2) a restriction on the project debt-equity ratio.

To determine the unleveraged (debt free) cash flow available to the project, the model uses a subroutine [CSHFLO] to calculate the average annual operating cash flow without interest charges [AAOCF], as follows:

```
      CALL CSHFLO (K,DP(K), CF(K))
      IF(K.GE.K61) TCF=TCF+CF(K)
   70 CONTINUE
      AAOCF = TCF/FLOAT(KOPS)
```

The cash flow available to service debt [DSCF] is computed by multiplying the average annual operating cash flow by the debt service cash flow factor [DSCFF]:

```
DSCFF = AAOCF * DSCFF
```

The level of debt used [XDBT] is determined through an iterative process. The initial debt level is equal to the operator specified increment [DBTI] for the iteration; the debt-equity ratio [DER] for this level of debt is computed. For this debt level, the annual before-tax interest charges [INT(K)] are calculated using a representative loan interest rate [IR] Since the outstanding debt [DEBT(K)] will be the highest during the first year of operations, using the series present worth factor for discounting an annuity, the required annual amortization payment [PMT] to retire this debt over the period of the loan [KLN] is calculated by the following equations:[9]

```
700 XDBT = XDBT + DBTI
720 DER = XDBT/(1.-XDBT)
    DO 740 K = K21, K51
    DEBT(K) = DEBT (K-1) + CAC(K) * XDBT
    INT(K) = DEBT(K) * IR
740 IF(K.EQ.K51) PMT = DEBT(K)*IR/(1.-(1.+IR)**(-KLN)
```

The payment thus calculated and the associated debt-equity ratio are tested for compliance with the loan covenants [DSCF and DERMAX, respectively] and, unless satisfied, the computation is repeated at the next level of debt.

When the restrictive covenants have been fully satisfied, the program uses the attained level of debt to compute the interest charges and the principal repayments [REPAY(K)] for the amortization period:

```
750 DBT=XDBT*100.
    DO 760 K-K51,KLIFE
    INT(K)=DEBT(K-1)*IR
    REPAY(K)=PMT-INT(K)
    IF(K.EQ.K10)REPAY(K)=DEBT(K-1)
    IF(K.EQ.K10)REPAY(K)=0.0
    DEBT(K)=DEBT(K-1)-REPAY(K)
760 IF (DEBT(K).LT.0) DEBT(K)=0.
```

The capital expenditures (less R&D and exploration expenditures, if capitalized) are then adjusted to reflect debt funding, as follows:

```
IF(K.GT.K2) CAC(K) = CAC(K) * (1.-XDBT)
```

Subtraction of the annual Interest Expense from Income before Interest and Tax gives Income before Tax and Credits [EBTC(K)].

iii. <u>Depletion.</u> Depletion, the initial computation in the subroutine [CSHFLO], is found using the percentage depletion method applied to a multi-mineral ore. Use of this method requires determination of the "gross income from mining". There is, at present, no established market for manganese nodules *per se*. The first saleable products expected from the operation considered for this study are the recovered minerals in electrolytic cathode form, suitable for subsequent alloying. For this reason, the proportionate profits method, as suggested by the IRS, is used to compute the proportion of gross revenues to treat as mining income.

The proportion allowable is the fraction of total annual operating costs representing annual mining sector operating costs. To recognize capital expenses, total annual depreciation expense and annual mining sector depreciation expense are added to the respective total and sector operating costs. The results of these additions are the total annual operating costs for depletion [TOCD(K)] and the annual mining sector operating costs [TCMP(K)]; they are computed as follows:

```
      IF(K.GT.K6) TOCD(K) = OC(K) + DP(K)
      IF(K.GT.K6) TCMP(K) = SOPCST(3) * INF(K,3) + DPS(3)
      IF(K.GE.K61.AND.K.LE.K12) TCMP(K) = DPS(3)
     C + SCEF(C4) * SOPCST(3) * INF(K,3)
      IF(K.EQ.K61)TCMP(K) = TCMP(K) + OWC * SOPCST(3) *
             INF(K,3)/LOC
      IF(K.LT.K61.OR.K.GT.K12) GO TO 65
      C4 = C4 + 1
   65 IF(K.EQ.KLIFE) TCMP(K) = (1.-WC) *SOPCST(3) * INF(K,3)
             +DPS(3)
```

From these costs, the annual depletion allowance for the multi-mineral nodule ore is calculated by applying the applicable percentage allowed for each recovered mineral to the appropriate portion of each mineral's annual gross revenues. This is done by the following pair of equations:

```
      DO 81 J = 1,NOM
   81 DPL(K) = DPL(K) + TCMP(K)/TOCD(K) * GRM(J,K) * XPCDPL(J)
```

If the nodules are to be considered a single metallic ore, the discrete mineral percentage allowance array [XPCDPL(J)] is redefined as that ore's allowable rate and the proportionate profits' method applied. In the event a representative market price for nodules is established, annual depletion allowance may be computed using it. Setting the depletion allowance basis index [MPPD] equal to 1, providing a representative market price for the ore [VLO], in dollars per ton, and defining the appropriate percentage for the ore classification [XDPL], the allowance is calculated as:

```
IF (MPPD.EQ.1) DPL(K) = XDPL * VLO * NAP
```

The annual production tonnage [NAP] sold then becomes the basis for the allowance.

The computed allowance is not permitted to exceed 50 percent of earnings before the allowance is applied and this restriction is provided by the following equation:

```
 IF((EBTC(K).GT.(0.0)).AND.  (DPL(K).GT.((0.5)*EBTC(K))))
1DPL(K) = (0.5) *EBTC(K)
```

Under IRS regulations, depletion allowance must be reduced annually by the recaptured excess of total exploration expenses over $400,000.[10] Therefore, given exploration expenditures are treated as a business expense, during the year of occurrence, as in the baseline evaluation, this adjustment is made by subtracting the recaptured excess exploration expense, apportioned equally over the production life of the operation, from the annual depletion allowance:

```
IF(MORTZ.EQ.O) DPL(K) = DPL(K) - (EXPX-.4/FLOAT(KOPS)
```

Subtraction of the computed allowance from Income before Tax and Credits gives Income before Tax Loss Credit [EBTS(K)].

iv. <u>Tax Loss Credit.</u> The IRS currently allows tax loss from any operating period to be carried forward up to seven years. Optionally, the loss can be carried back to the third tax year preceding the year of sustainment.[11] In the model, this carryback option is foregone. Annual loss [XPL(K)], if incurred, is cumulated, by year, using the tax loss credit index

[KT]. When a profitable year occurs following one or more losses, the income before tax loss credit is adjusted by successive annual credits [TS(K)] until it equals zero or the account is exhausted. If the former occurs first, the unused balance is restored to the account for application during the remaining valid years. The equations which apply this credit are:

```
   IF((K-KT).GT.(7)) KT=(K-7)
   IF(EBTS(K).LE.(0.0)) GO TO 84
81 IF(KT.EQ.K) GO TO 84
   TS(K) = TS(K) + XPL(KT)
   KT=KT+1
   IF((EBTS(K)-TS(K)).GT.(0.0)) GO TO 83
   KT=KT-1
   XPL(KT)=TS(K)-EBTS(K)
   TS(K)=TS(K)-XPL(KT)
```

Subtraction of the annual Tax Loss Credit from Income before Tax Loss Credit gives Income before Tax [EBT(K)]. Application of the marginal tax rate [TR1] to this remainder gives Tax before Investment Credit [TBIC(K)]:

```
TBIC(K) = TR1 * ETB(K)
```

v. Investment Credit. To use the tax credits earned for qualifying annual investment expenditures (see section b of this appendix), the model employs the same algorithm used for tax loss credit. The annual earned credit [XCAC(K)] is cumulated, by year, using the investment credit index [KI]. A particular year's credit [ICDT(K)] is applicable to the annual tax liability during any or all of the seven successive years after it is earned. When there is an outstanding tax liability and the investment credit account is not exhausted, successive years' credits are applied until the outstanding liability is reduced by 50 percent or the account is exhausted.

The equations which apply the credit are given below:

```
   IF((K-KI).GT.(7)) KI=(K-7)
85 IF(KI.EQ.K) GO TO 87
   ICDT(K) = ICDT(K)+XCAC(KI)
   KI=KI+1
```

```
IF((TR2*EBT(K)-ICDT(K)).GE.0.) GO TO 85
KI=KI-1

ICDT(K)=ICDT(K)-XCAC(KI)
```

vi. Tax. Application of earned investment credit to the annual tax liability reduces the annual tax payment [TAX(K)] and is done by the following equation:

```
87 TAX(K) = TBIC(K) - ICDT(K)
```

vii. Net Income. When the annual tax payment is subtracted from the Earnings before Tax, the remainder is the Net Income [PL(K)] from the project. As noted in iv above, if a net loss is sustained, it is entered into the Tax Loss Credit account for subsequent recovery:

```
PL(K) = EBT(K) = TAX(K)
IF(PL(K).LT.(0.0)) XPL(K) = -PL(K)
```

e. Annual Net Cash Flow

As illustrated in Figure III-10, Chapter III, the annual net cash flow is the remainder of gross revenues after all costs, tax payments and investment outlays have been considered. In standard financial analysis, this is equivalent to the algebraic sum of net income and all non-cash expenses (i.e., depreciation, depletion and tax loss credit) less investment expenditures. Within the program, the annual cash flow [XCF] computation concludes the subroutine [CSHFLO]:

```
EQTY(K) = CAC(K) + REPAY(K)
TICAC = TICAC + EQTY(K)
XCF = PL(K) + XDP + DPL(K) + TS(K) - EQTY(K)
RETURN
```

The sum of all annual investments, whether direct capital expenditures or principal repayments, represent the equity capital [EQTY(K)] infused each year. The annual cumulative total of these expenditures is identified as year-to-date total invested capital [TICAD].

With the annual equity infusion, the cumulative total invested capital and the annual cash flow, calculated for each year of project life, various economic return assessments can be made.

4. Economic Return Estimation

a. Private Sector

The estimates of economic return to the private sector are developed using the standard capital budgeting technique of discounting cash flows. The results are expressed in two distinct measures: 1) the net present value, and 2) the internal rate of return. A third, non-time adjusted measure, the project payback period, is also calculated; frequently, the private sector interprets this measure of capital recovery as the period during which the investment is at risk.

i. Net Present Valuation. The net present value [NPV(K)] is determined by the program after the project cash flow stream has been estimated. Doing so permits the NPV evaluation to be conducted either at the specific discount rate, over a range of discount rates, or using both.

Net present value is defined as the sum of the present values of the successive annual net cash flows over the entire life of the project and is expressed by the following mathematical equation:[12]

$$NPV = \sum_{K=1}^{n} CF_K / (1+i)^{(k-1)}$$

where

NPV = project net present value

CF_K = annual cash flow in year k

i = marginal cost of capital

and n = life of the project.

The valuation is initiated by specifying a single discount rate [SLDR] if desired. If discounting over a range of rates, the upper and lower limits [TLDR and BLDR, respectively] are set equal to the end values of the desired range and the discount rate increment [DRI] defined. If both a specific rate and a range of rates are desired together, the former must be contained within the range and be equivalent to one of the incremented values. If the range is not desired, the range limits must be set equal to zero:

```
   IF(SLDR.EQ.0.) NPV(KLIFE) = 999E10
   IF(SLDR.EQ.0.) SLDR = 999E10
   NDRR = 0
   XLDR = TLDR
   DRR = TLDR - BLDR
   IF(DRR.EQ.0.) NDRR = 1
   IF(NDRR.EQ.1) SLDR = XLDR
   IF(NDRR.NE.1) NDRR=IFIX(DRR/DRI+1.)
   DO 96 ND=1,NDRR
   XNPV=0.
   SARAY(ND,1) = XLDR
   DO 94 K = 1, KLIFE
   XPV = CF(K)/((1. + XLDR/100.) ** (K-1) * INF(K,4))
   IF(XLDR.EQ.SLDR) PV(K) = XPV
   XNPV = XNPV + XPV
   IF(XLDR.EQ.SLDR) NPV(K) = XNPV
   IF(K.EQ.KLIFE) SARAY (ND,L+1) = XNPV
94 CONTINUE
96 XLDR = XLDR - DRI
```

The output from the valuation is provided in tabular format with the columns corresponding to the various discount rates and the rows corresponding to the various scenarios evaluated.

ii. <u>Internal Rate of Return.</u> The internal rate of return is determined by an iterative process which uses the same computational logic as the net present value, but defines the relevant variables differently. Starting with the initial discount rate, [DR], equal to zero, discounting of the project cash flow stream is done at successive rates [XDR], incremented by a tenth of a percent (0.01%), until the associated NPV [RNPV] is approximately zero. The rate at which this event occurs is defined as the project's internal rate of return [SIROR]:

```
   DR=0.
   DR=DR + . 0001
```

```
      IF(DR. GE. 0.5) GO TO 994
      XDR = 1. + DR
      RNPV = 0.
      DO 992 NK = 1, KLIFE
  992 RNPV = RNPV + CF(NK)/(XDR**(NK-1))
      IF(RNPV. GT.0.) GO TO 990
  994 SIROR = 100.* DR
```

iii. Payback Period. The payback period [SPB] is defined as the number of years required to recover an investment once operations have commenced. It is computed by adding the successive annual cash flows until the sum [TSPB] equals the total amount of capital investment:

```
      DO 92 K=1, KLIFE
      IF(C6.EQ.1) GO TO 92
      IF(K.GT.K6) TSPB = TSPB + CF(K)
      IF(TSPB.GT.TICAC) SPB = FLOAT(K-K61) + ((CF(K) - TSPB +
                 TICAC)/CF(K))
      YSPB = YEAR(IFIX(SPB) + K61
      IF(YSPB. GT. YEAR(K61)) C6=1
   92 CONTINUE
      IF(SPB.EQ.0) SPB = 999E10
      IF(YSPB. GT. YEAR(KLIFE).AND.C6.EQ.0) YSPB=999E10
```

The actual year of payback [YSPB] is also computed.

b. Public Sector

The annual income to the public sector realizeable from ocean mining is represented by the annual tax liability the project incurs.[13] In evaluating this revenue stream, the public decision-maker usually applies the discounting method, but applies a different discount rate, frequently called the social discount rate [SDR]. Traditionally, this rate has been determined by the borrowing rate of the government; however, arguments are presented for using rates similar to those used by the private sector.[14] For this study, evaluation of public income is based upon discounting the stream of annual tax revenue generated from the project at the social discount rate of ten percent.

The total annual tax revenue generated is equal to the annual federal corporate tax payment [TAX(K)] plus the annual state and local taxes payment [STAXR]. When discounted, the annual discounted tax revenue [DSCTAX(K)] is obtained. Over the life of the project, the sum of these successive annual discounted tax revenues is equal to the cumulative discounted tax [SDTAX(K)] in any year. Computed for the last year of the project, this sum is the total income to the public sector from the project. The determination of this quantity is done by the following series of equations:

```
IF(K.GT.K6) STAXR = STXRT * SCPCST(5)
DSCTAX(K) = (TAX(K) + STAXR)/(1.+SDR/100.) ** (K-1) *
            INF(K,4))
XDTAX = XDTAX + DSCTAX(K)
SDTAX(K) = XDTAX
```

c. National Income

Evaluation of a large investment's economic return to the nation requires consideration of the net benefits to be derived from the project and the distribution of these benefits to the designated recipients.[15] These are the traditional economic concerns for efficiency and equity, respectively, addressed by welfare economics. It is beyond the scope of this study to fully develop the considerations for opportunity costs, market structure, consumer sovereignty and externalities which underlie this area of economics. For this study, the national economic return measures only the net benefits which accrue to the nation as a whole, [ERENT(K)], represented as the sum of annual returns to the private sector and the annual income to the public sector, culminated over the life of the project. In the model, this determination is made by the following series of equations:

```
IF(K.GT.K6) STAXR = STXRT * SCPCST(5)
SURPLS(K) = (CF(K) * USFRAC)/(1. + SDR/100.) **
            (K-1) * INF(K,4)
ECRNT = ECRNT + DSCTAX(K) + SURPLS(K)
ERENT(K) = ECRNT
IF(K.EQ.KLIFE) TRENT(NR,L) = ERENT(K)
```

In the second equation above, the fraction of domestic capital invested [USFRAC] is equal to unity on the assumption that, for the first generation project, all net benefits accrue directly to the U.S.

Table E-2, Initial Values of Input Variables for Financial Analysis

Variable	Description	Value	Units
AP	'A priori' Probability	5*.1 5*.075 5*.05 35*0.0	
BLDR	Lower Limit on Discount Rate Range	8	Percent
CAPFC	Capital Allocation Factor	10*1.	
CCSF	Capital Cost Sensitivity Factor	30*1.	
DBTI	Debt Increment	2	Percent
DERMAX	Maximum Allowed Debt Equity Ratio	1:1	
DLY	Delay Period Lengths	5*0	Years
DPLA	Ore Depletion Allowance	0	Percent
DRI	Discount Rate Increment	2	Percent
DSCFF	Debt Service Cash Flow Factor	0.67	
IG	Investment Guarantee Selector	0	
KDP	Group Depreciation Period		
	Mining Equipment	10	Years
	Transport Equipment	18	Years
	Process Equipment	14	Years
KDPMAX	Maximum Depreciation Period	20	Years
KE	Exploration Period Startup	2	Years
KINVST	Investment Period	3	Years
KLN	Amortization Period	10	Years
KPE	Exploration Period	2	Years
KPP	Prospecting Period	2	Years
KOPS	Operating Period	25	Years
KOP1	Initial Operating Period	0	Years
KPI	Preinvestment Period	2	Years
KRD	Research & Development Period	2	Years

Variable	Description	Value	Units
KSU	Startup Period	0	Years
KV1	Initial Investment Period	0	Years
LOAN	Loan Repayment Method	0	
METH	Method of Depreciation	2	
MORTZ	Amortization Selector	0	
MPPD	Depletion Allowance	0	
MV	Metal Prices		
	Nickel	2.00	$/lb
	Copper	0.71	$/lb
	Cobalt	4.00	$/lb
N	Number of Sensitivity Analyses	0	
NG	Number of Groups in Each Sector	6	
NGL	Graph Format Control	0	
NOM	Number of Minerals Recovered	3	
NRUNS	Number of Runs	1	
NS	Number of Sectors in Cost Estimation	5	
NSA	Sensitivity Analysis Selector	0	
NTSA	Sensitivity Analysis Designator	0	
NU	New or Used Assets Designator	19*0,1,10*0	
OCSF	Operating Cost Sensitivity Factor	30*1.	
OOG	Graph Selector	0	
OO1	Output Format Control	1	
PCDPL	Mineral Percentage Depletion		
	Nickel	14	Percent
	Copper	14	Percent
	Cobalt	14	Percent
PSV	Project Salvage Value	0	Percent
RDX	Research & Development Expense	50	Million Dollars

Variable	Description	Value	Units
SCEF	Startup Period Cost Efficiency	5*1.	
SDR	Social Discount Rate	10	Percent
SLDR	Specified Discount Rate for Study	0	Percent
SREF	Startup Period Recovery Efficiency	5*1.	
STXRT	State Tax Rate	1	Percent
SVNP	Salvage Value of New Project	50	Percent
SVP	Sector Salvage Value	30*0.	Percent
TLDR	Upper Limit on Discount Rate Range	24	Percent
TR	Tax Rate	48	Percent
USFRAC	Fraction of U.S. Investment	1.	
V	Sensitized Variable Designator	0	
VLO	Value of Landed Ore	23.60	Dollars
W	Sensitized Variable Descriptor	Blank	
WRD	Recovered Mineral Descriptor		
	Nickel		
	Copper		
	Cobalt		
WRDZ	Reserved Mineral Symbol		
	Ni		
	Cu		
	Co		
XICDT	Investment Credit, Post 1980	7	Percent
XIF	Escalation Index		
	Revenues	0	Percent
	Investment	0	
	Costs	0	Percent
	Discount Rate	0	Percent
XIR	Term Loan Interest Rate	10	Percent
XTICDT	Temporary Investment Credit	10	Percent
YEAR 1	First Year of Project Activity	1976	

Appendix E Notes

1. The financial analysis section used for this study was developed by extensive revision to the model developed by A.E. Copstaff, Jr. in "Profitability of the Ocean Mining Industry and Competition" in Law of the Sea: Conference Outcomes and Problems of Implementation, Edward Miles and John King Gamble, Jr., Editors (Cambridge: Ballinger, 1977).

2. For complete details regarding this system, refer to IRS Publication No. 534, Tax Information on Depreciation, pp. 8, 17, 25, and 29.

3. A detailed explanation of the effects of inflation on the discount rate employed in capital budgeting is contained in "Capital Budgeting and Inflation," Chapter 16 of The Capital Budgeting Decision by Harold Bierman, Jr. and Seymour Smidt (4th Edition, Macmillan, 1975), pp. 313-317.

4. A comprehensive review of the impact of startup costs on an operation is provided in Section C-2.300 of the American Association of Cost Engineers' Cost Engineers' Notebook, issued in June 1977 as an insert in the AACE Bulletin, vol. 19, no. 3.

5. Capitalization of these expenditures is evaluated by specifying the capitalization designator [MORTZ] equal to 1. Doing so allows the R&D expenditures of the pre-investment period and the expenditures during the exploration period to be considered capital investment and recovered in a manner similar to straight-line depreciation. In the model, capitalization of this expenditure is ignored when computing the project debt resulting from financing, equipment procurement with intermediate term loans.

6. IRS publication No. 534, Tax Information on Depreciation, 1977 Edition, p. 6.

7. Ibid., p. 6.

8. Ibid., p. 7.

9. The derivation of the series present worth factor can be found in Accounting: A Management Approach by M.J. Gordon and G. Schillinghlaw (Homewood: IRWIN, 5th Edition, 1974), pp. 749-750.

APPENDIX F. NOTE ON PERCENTAGE DEPLETION

The Internal Revenue Code provides that in the "case of mines, oil and gas wells, other natural deposits, and timber, there shall be allowed as a deduction ... a reasonable allowance for depletion ..."[1] The purpose of the depletion allowance, as construed by the courts, is to:

> "compensate [the] owner of wasting mineral assets for [the] part exhausted in production, so that when minerals are gone, [the] owner's capital and capital assets remain unimpaired"[2]

Court cases have also read into the allowance the goal "to encourage exploration of natural resources"[3] which are exhausted upon recovery, but have said it is "not to be considered as a reward ... for risk inherent in ... extraction."[4]

Depletion therefore concerns the exhaustion of natural resources, and may be distinguished from depreciation, which goes to the usable life of tangible property used in a business.[5] The taxpayer must have an "economic interest" in the operation in question in order to be eligible.[6]

The depletion allowance has been judicially described as a matter of legislative grace.[7] Most likely, Congress will be called upon to decide whether or not the allowance will apply to deep seabed mining. This eventuality is heralded implicitly by the Murphy-Breaux bill. That bill, one of the leading contenders among several dealing with deep ocean mining, states in section 107 that:

> "For purposes of the laws of the United States relating to ... taxes, all hard mineral resources recovered under the authority of a permit ... issued under section 103 of this title shall be deemed to have been recovered within the United States."[8]

In the past, Congress has, through the Internal Revenue Code, tightly held on to decision-making as to the minerals eligible for percentage depletion and the rates to be applied. The courts, in contrast, have apparently taken the lead in defining "economic interest", a term critical to application of the allowance. It is probably safe to say that the present Code does not yet reflect Congress's formal thinking on the status of nodules. In fact, one might argue from what legislative history exists that it has not yet formally anticipated the prospect of copper, nickel, cobalt and manganese being taken from the seabed.

Under present law, two issues exist which appear to require resolution before the question of coverage can be satisfactorily answered: 1) would the industry operator have the required "economic interest"; and, 2) are deepsea nodules covered under 26 USC 613, that section of the IRS Code specifying coverage and percentage rates?

A. Possible Coverage Under Section 613

Section 613 of the Internal Revenue Code sets out the minerals for which Congress has authorized deduction of a depletion allowance and the percentage rate allowed. It is arguable that manganese nodules would be allowed a deduction under the existing provisions. It is also arguable that they would not.

The Code provides a depletion allowance of 22% for nickel, cobalt and manganese[9] and a 15% allowance for copper,[10] provided these minerals are from deposits in the United States. A 14% allowance is provided "metal mines" where the above provisions do not apply, covering deposits outside the U.S.[11] Still other percentage deductions are allowed other minerals, not relevant to this discussion. Finally, a 14% allowance is allowed "all other minerals", including but not limited to a long list such as calcium carbonates, diatomaceous earth, magnesium carbonates, and mollusk shells.[12] However, for purposes of this 14% allowance provision, "all other minerals" does not include "minerals from sea water, the air or similar inexhaustible sources".[13]

Two issues are raised. The first is whether the statute, taken as it stands, can be read to include nodules as being "deposits in the United States". On the face of it, they are not. And as indicated earlier, this view is implicitly recognized by at least one major deep ocean bill before Congress in which it is found necessary to specifically state that nodules shall be deemed to have been recovered within the United States.

The second issue is whether nodule deposits are included under "metal mines" not in the U.S., for which a 14% allowance is provided in 613(b)(3). Copper, nickel, cobalt and manganese are metals. Is a nodule recovery site a mine? The statute makes a distinction by reference in its opening sentence to "mines, oil and gas wells, other natural deposits, and timber". Further, the idea that "mines" is a different and narrower term than "natural deposits" finds some support in at least one court case in different context, now over thirty years old:

> "The word 'mines' ... is limited to natural deposits ... being included in [the] concluding classification of 'natural deposits'."[14]

Finally, there are the questions of whether nodules would be included among the "all other minerals" category for which a 14% allowance is provided in 613(b)(7), and if so, whether they would then fall under the exclusion applying to minerals from sea water. Although by the statute's terms, "all other minerals" is not limited to those enumerated, it does seem significant that nickel, cobalt, copper and manganese are not listed here, but are all explicitly included in the earlier assignments of percentages.[15]

Congress's rationale in excluding minerals from sea water and air turned on their inexhaustible nature. As pointed out above, depletion was intended to compensate owners of wasting mineral assets.[16] If the assets were from an inexhaustible source, the rationale was absent. Nodules do not neatly fit within the exclusionary rationale, however. They do accrete from the sea water, but very slowly; so slowly that while plentiful, they cannot really be considered inexhaustible.

The only apparent interpretation given this exclusion concerned mineral deposits in the Great Salt Lake which the IRS declared to be inexhaustible and excluded by this clause,[17] only to have Congress restore the deposits to eligibility in an amendment to the Code four years later.[18]

The problem is that in 1954, Congress either did not imagine that copper, nickel, cobalt and manganese would be commercially recoverable from the seabed in composite lumps that accreted over a long period of time from minerals in the ocean water, or recognized that it did not need to deal then with the issue.

B. The Nature of an Economic Interest

While the above discussion focuses on the eligibility of the mineral for percentage depletion, the issue of economic interest for the most part deals with who is eligible to claim the deduction. In most cases it is a given that the mineral deposit in question qualifies and the issue is whether or not the claim to a deduction of a particular party is valid. A typical court statement requires that:

> "... the taxpayer has acquired, by investment, any interest in the oil [mineral] in place, and secures, by any form of legal relationship, income derived from the extraction of the oil [mineral], to which he must look for a return of his capital."[19]

The test, then, is twofold -- a capital investment in the mineral in place and a return on the investment which is realized solely from the extraction of the mineral.[20] Availability of the allowance does not depend upon "the particular form of the taxpayer's interest in the property";[21] legal title is not required, and may not even be important, according to the U.S.

Court of Claims.[22] "The law of depletion requires an economic, rather than a legal interest in the mineral deposit."[23]

These perspectives would suggest that the issue of whether ocean miners will "own" either the sites or the minerals, through a claims and patent process or other similar legal mechanisms would not be controlling under existing law.

Nevertheless, the nature of the deep ocean miner's investment in the mineral in place would appear important under existing law, especially since it is unlikely to be either in the property, e.g., the seabed, or in the form of a lease.[24] Here the cases appear to split, with major issues being the claimant's control over production or extraction and the claimant's being essential to the production.

In the 1937 case of Helvering v. Bankline Oil Co.,[25] the Supreme Court denied an allowance to a gas processor who purchased "wet gas" and then treated it at least in part because it "did not produce [the gas] and could not compel its production."[26] The principle was applied by the Court of Claims to another purchaser of gas in CBN Corporation v. U.S. 364 F.2d 393(1966). In the interim, the Supreme Court also denied an allowance to coal mine operators mining under contract to the owners. A long list of reasons for the denial included:

> "(1) that petitioners' investments were in their equipment, all of which was movable -- not in the coal in place; (2) that their investments in equipment were recoverable through depreciation -- not depletion; (3) that the contracts were completely terminable without cause on short notice;...(5) that the coal at all times, even after it was mined, belonged entirely to the landowners and that petitioners could not sell or keep any of it...and (7) that petitioners, thus, agreed to look only to the landowners for all sums to become due them..."[27]

On the other hand, the Supreme Court has approved an allowance to taxpayers who had an interest in land, which though not the land from which the mineral (offshore oil) was produced was, nevertheless under a complex California law, found by the Court to make the owners "essential parties" to any drilling operations", to place them in a "controlling position" over production.[28]

This principle was applied by the Court of Claims in 1965 to an investment in equipment under circumstances likely to have some parallel to deep ocean mining. In Food Machinery and Chemical Corp. v. U.S.,[29] claimant had made a $20 million investment in electric furnaces isolated so they could not be used for other purposes, which the court found were an essential and economically strong element in the mining process. Later, in another case, the same court, referring back to the FMC case, emphasized the essentiality of the equipment and commented that:

> "The requisite of essentiality to the drilling or extraction operation seems now to be well established"[30]

The Tax Court also followed the Southwest principle in finding in favor of a sand and gravel company dredging a state-owned river bed which "owned and used (a) parcel of riparian land ... which gave it exclusive physical and economic control of such dredging ... and such use was indispensible to removal" of the sand and gravel at the locations the company was working.[31]

The analysis of the above cases suggests that if current case law were to be the guide, the availability of percentage depletion allowance to the miner might turn on the essentiality of the equipment and other services (exploration, equipment design, etc.) to the operation, the relative permanency or movability of the mining equipment, and the exclusivity of the miner's right to control the mining operation. Once again, there would be an advantage to having a clear Congressional statement on the issue.

Appendix F Notes

1. 26 U.S.C. 613.

2. Paragon Jewel Coal Co. v. C.I.R., 380 U.S. 624, 85 S. Ct. 1207 (1965).

3. Weirton Ice & Coal Supply Co. v. C.I.R. 231 F.2d 531 (1956).

4. Stillwell v. U.S., 250 F.2d 736 (1957).

5. Arkansas-Oklahoma Gas Co. v. C.I.R., 201 F.2d 98 (1953).

6. Food Machinery and Chemical Corp. v. U.S., 348 F.2d 921 (1965).

7. C.I.R. v. Iowa Limestone Co., 269 F.2d 398 (1959).

8. H.R. 3350, 95th Cong., 1st Sess., Proposed Subcommittee Print, July 7, 1977.

9. 26 U.S.C. 613(b)(1)(B).

10. 26 U.S.C. 613(b)(2).

11. 26 U.S.C. 613(b)(3).

12. 26 U.S.C. 613(b)(7).

13. _Id_.

14. Consolidated Chollar Gould and Savage Mining Co. v. C.I.R., 133 F.2d 440 (1943).

15. The argument might be made that nodules comprise a new aggregate mineral, something more than their elements, but industry and IRS practice of recognizing composite ores when found together in the same deposit would seem to set this issue aside.

16. _Supra_ note 2.

17. Rev. Rul. 65-7, CB 1965-1, p. 254.

18. By adding to subsection 613(b)(7) as specific provision creating an exception to the exception.

19. Palmer v. Bender, 287 U.S. 551, 53 S. Ct. 225 (1933).

27. Parsons v. Smith, 359 U.S. 222, 79 S. Ct. 656 (1959); see also Paragon Jewel Coal Co. v. C.I.R., 380 U.S. 624, 85 S. Ct., 1207 (1965).

28. C.I.R. v. Southwest Exploration Co., 350 U.S. 308, 76 S. Ct. 395 (1956).

29. Food Machinery and Chemical Corp. v. U.S. 348 F.2d 921 (1965).

30. CBN Corp. v. U.S., 364 F.2d 393 (1966).

31. The Oil City Sand and Gravel Co. v. C.I.R., 32 Tax Court 31 (1959).

20. Food Machinery and Chemical Corp. v. U.S., 348 F.2d 921 (1965).

21. Supra note 19 at 557.

22. National Steel Corp. v. U.S., 364 F.2d 375 (1966).

23. Commissioner v. Southwest Exploration Co., 350 U.S. 308, 316 (1956); National Steel Corp. v. U.S., supra note 22.

24. Current U.S. legislative proposals provide for licenses for exploration and permits for commercial recovery (e.g. Murphy-Breaux bill section 102, H.R. 3350, 95th Cong., 1st Sess., Proposed Subcommittee Print, July 7, 1977.) The Deepsea Ventures claim filed in November 1974 ran to mining rights of a deposit of nodules, but not to territorial claim to the seabed or subsoil underlying the deposit (Deepsea Ventures, Inc., Notice of Discovery and Claim of Exclusive Mining Rights etc., Nov. 14, 1974). It is somewhat ironic that the Law of the Sea proposals for an International Seabed Resource Authority may provide the most likely basis for a miner to acquire some recognized property right, based on the Authority's receipt of a delegation of authority to allocate the common heritage of mankind.

25. Helvering v. Bankline Oil Co., 303 U.S. 362 (1937).

26. Id. at 368.

APPENDIX G, DOCUMENTATION

This appendix provides information concerning the computer program used in the study. A flowchart of the model is shown in Figure G-1. There follows a sample output of the baseline model.Finally, a table listing the NPV for the analyses made in Chapter VI is provided

The program consists of three major elements: the cost estimation section, the financial analysis section, and the output and display section. The program is written in FORTRAN IV and has been used in conjunction with the WATF IV compiler.

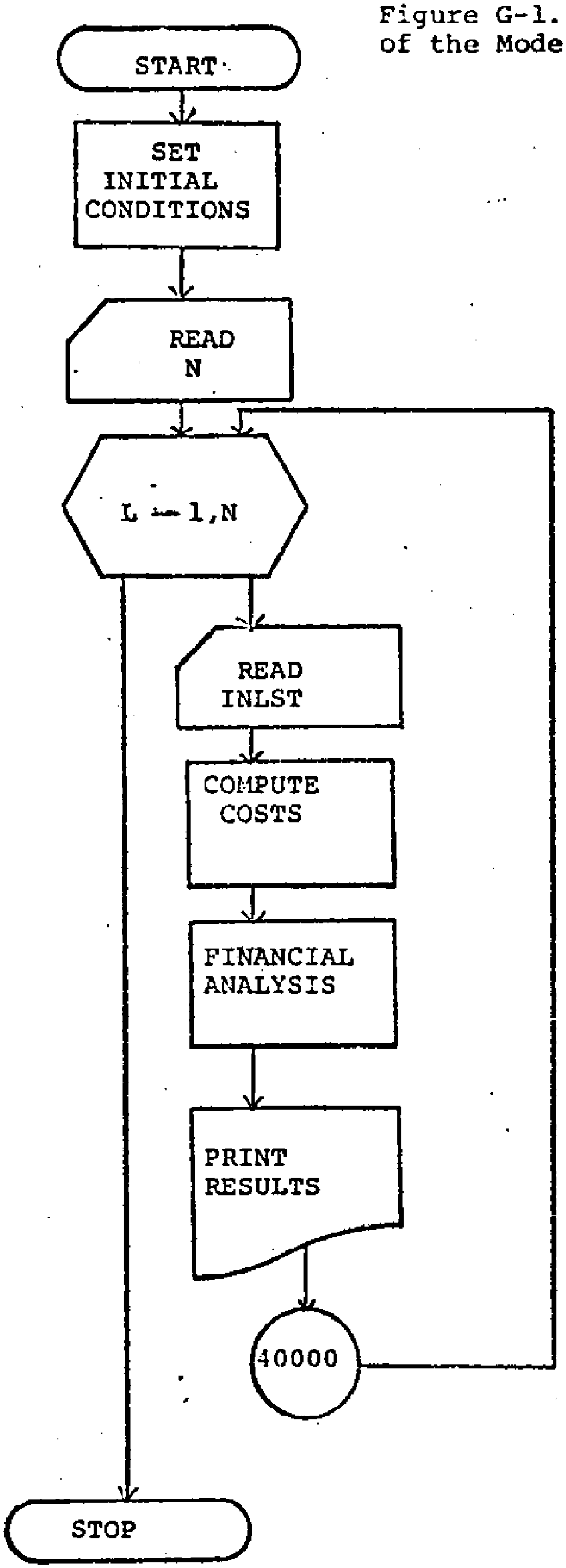

Figure G-1. Flowchart of the Model

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($1976 x 1 MILLION)

(at various discount rates)

Figure or Table	24.00	22.00	20.00	18.00	16.00	14.00	12.00	10.00	8.00	IROR	PAYBACK PERIOD
VI-1, Baseline	-58.73	-43.63	-23.89	2.06	36.43	82.39	144.60	229.99	349.07		
VI-2, Total Revenues +25%	4.79	29,46	60.90	101.35	153.95	223.22	315.75	441.36	614.89		
VI-2, Total Revenues -25%	-137.57	-133.65	-127.43	-118.01	-104.16	-84.04	-54.99	-12.97	48.15		
VI-3, Ni Price +25%	-16.30	5.13	32.60	68.13	114.54	175.89	258.11	370.03	525.04	22.44	4.1
VI-3, Ni Price -25%	-108.51	-100.52	-89.38	-73.98	-52.75	-23.40	17.44	74.76	156.21	12.78	9.2
VI-4, Co Price +25%	-51.40	-35.23	-14.17	13.42	49.87	98.54	164.30	254.47	380.10	18.91	5.1
VI-4, Co Price -25%	-68.52	-54.84	-36.83	-13.02	18.69	61.29	119.15	198.84	310.26	17.12	5.8
Co up 50% (to $6.00)	-40.97	-23.27	-0.36	29.50	68.76	120.98	191.31	287.45	421.06	19.97	4.7
VI-5, Annual Production Rate, 3.5 million TPY	-48.63	-30.27	-6.44	24.72	65.79	120.51	194.34	295.40	436.04	19.54	4.9
VI-5, Annual Production Rate, 2.5 million TPY	-71.59	-60.39	-45.54	-25.81	0.57	36.14	84.59	151.46	245.15	16.05	6.2
VI-6, Slow Startup	88.68	-75.80	-58.46	-35.12	-3.57	39.34	98.25	180.07	295.31		
VI-7, 2% Ore Grade (1.1% Ni, .9% Cu, .024% Co)	-119.72	-113.89	-105.42	-93.34	-76.27	-52.24	-18.33	29.84	98.91		
VI-8, Total of Costs +25%	-88.21	-77.20	-62.41	-42.53	-15.71	20.72	70.66	139.93	237.39		
VI-8, Total of Costs -25%	-33.51	-14.78	9.40	40.84	82.10	136.88	210.55	311.15	450.83		
VI-9, Energy Costs, +25%	-66.94	-53.01	-34.70	-10.49	21.71	64.95	123.66	204.48	317.46		
VI-9, Energy Costs, -25%	-52.87	-36.94	-16.18	11.03	47.00	95.03	159.95	248.99	373.07		
VI-10, Labor Costs, +25%	-69.15	-55.53	-37.59	-13.85	17.76	60.24	117.95	197.44	308.60	17.06	5.9
VI-10, Labor Costs, -25%	-50.82	-34.59	-13.46	14.21	50.77	99.56	165.49	255.88	381.81	18.96	5.1
VI-11, Materials Costs, +25%	-66.24	-52.19	-33.73	-9.35	23.07	66.60	125.69	207.02	320.70	17.37	5.7
VI-11, Materials Costs, -25%	-53.60	-37.79	-17.18	9.85	45.58	93.30	157.83	246.32	369.66	18.67	5.2

Figure or Table	24.00	22.00	20.00	18.00	16.00	14.00	12.00	10.00	8.00	IROR	PAYBACK PERIOD.
VI-12, Fixed Costs +25%	-63.41	-48.98	-30.06	-5.11	28.04	72.49	132.80	215.76	331.67	17.65	5.7
VI-12, Fixed Costs -25%	-56.20	-40.76	-20.59	5.88	40.90	87.72	151.04	237.92	359.04	18.40	5.3
VI-13, Total Capital Costs +25%	-103.49	-90.85	-73.78	-50.73	-19.52	22.99	81.43	162.68	277.20		
VI-13, Total Capital Costs -25%	-17.39	-0.18	21.84	50.25	87.28	136.15	201.54	290.41	413.30		
VI-14, Processing Equipment +25%	-76.38	-62.23	-43.52	-18.69	14.46	59.10	119.85	203.65	320.98		
VI-14, Processing Equipment -25%	-41.34	-25.31	-4.58	22.44	57.97	105.21	168.81	255.72	376.47		
VI-15, Utilities +25%	-67.38	-52.87	-33.79	-8.58	24.95	69.97	131.12	215.29	332.98		
VI-15, Utilities -25%	-52.42	-37.07	-17.09	9.10	43.72	89.93	152.38	238.01	357.30		
VI-16, Transport Ships +25%	-65.20	-50.63	-31.48	-6.20	27.40	72.49	133.69	217.93	335.67		
VI-16, Transport Ships -25%	-54.49	-39.21	-19.28	6.85	41.41	87.57	149.97	235.55	354.81		
Table VI-2, Mineshop +25%	-64.53	-49.85	-30.59	-5.18	28.57	73.83	135.23	219.69	337.68		
Table VI-2, Mineship -25%	-55.17	-39.99	-20.18	5.83	40.23	86.21	148.42	233.77	352.78		
Table VI-2, Pipehandling System +25%	-60.11	-45.04	-25.32	0.60	34.95	80.90	143.11	228.52	347.63		
Table VI-2, Pipehandling System -25%	-57.35	-42.22	-22.45	3.52	37.90	83.87	146.08	231.46	350.51		
Table VI-2, Lift System +25%	-59.19	-44.09	-24.36	1.58	35.94	81.90	144.11	229.51	348.60		
Table VI-2, Lift System -25%	-58.28	-43.16	-23.41	2.54	36.91	82.88	145.09	230.48	349.55		
Table VI-2, Waste Disposal System +25%	-60.20	-45.15	-25.47	0.42	34.73	80.64	142.79	228.13	347.16		
Table VI-2, Waste Disposal System -25%	-57.26	-42.10	-22.31	3.70	38.12	84.14	146.41	231.85	350.98		
VI-17, 1 Year Pre-Investment Delay	-56.90	-44.84	-28.51	-6.37	23.77	65.12	122.44	202.89	317.47		
VI-17, 2 Year Pre-Investment Delay	-54.61	-44.86	-31.21	-12.15	14.49	51.94	105.01	181.09	291.65		

Figure or Table	24.00	22.00	20.00	18.00	16.00	14.00	12.00	10.00	8.00	IROR	PAYBACK PERIOD
VI-18, 1 Year Pre-Operations Delay	-99.62	-87.37	-70.63	-47.79	-16.58	26.32	85.78	169.15	287.68		
VI-18, 2 Year Pre-Operations Delay	-134.23	-125.15	-111.85	-92.73	-65.48	-26.70	28.68	108.33	224.16		
VI-19, Combined Delay, 1 Year Each	-89.78	-80.58	-67.34	-48.49	-21.79	16.09	70.08	147.74	260.78		
VI-19, Combined Delay, 2 Years Each	-105.46	-101.74	-94.85	-83.34	-65.02	-36.61	6.96	73.60	175.99		
VI-20, Skewed Capital Investment	-55.81	-43.70	-27.35	-5.22	24.90	66.21	123.45	203.77	318.17		
VI-21, 6% Inflation	-60.25	-45.36	-25.85	-0.16	33.92	79.57	141.42	226.40	345.00	17.99	4.4
VI-22, No Debt	-120.13	-103.71	-81.88	-52.83	-14.09	37.87	108.18	204.35	337.68	15.41	4.0
VI-22, 67% Debt	-38.88	-24.24	-5.22	19.68	52.57	96.52	156.04	237.87	352.25	19.53	6.2
VI-23, Amortized R&D	-62.87	-48.30	-29.16	-3.89	29.70	74.79	136.03	220.35	338.27	17.74	6.8
VI-24, Straightline Depreciation	-64.24	-49.59	-30.31	-4.82	29.12	74.74	136.73	222.13	341.55	17.68	5.9
VI-24, Sum of Year's Digits Depreciation	-56.71	-41.35	-21.33	4.92	39.60	85.88	148.37	233.98	353.14	18.34	5.2
VI-25, 22% Depletion for NI & Co, 14% for Cu	-57.79	-42.47	-22.44	3.88	38.75	85.41	148.58	235.32	356.34		
VI-25, No Depletion	-65.82	-51.96	-33.73	-9.66	22.36	65.34	123.71	204.08	316.45		

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

CAPITAL COST SUMMARY

MINING SECTOR			
PLATFORM	53.77		
PIPE HANDLING SYSTEM	20.66		
POWER PLANT	6.82		
LIFT SYSTEM	9.53		
NAVIGATION AND CONTROL	5.00		
OTHER COSTS	0.00		
TOTAL MINING SECTOR COSTS		95.79	
TRANSPORT SECTOR			
SHIPS	53.25		
SLURRY SYSTEMS	1.80		
TOTAL TRANSPORT COSTS		55.05	
PROCESSING SECTOR			
PROCESS EQUIPMENT	199.34		
UTILITIES	83.57		
SITE DEVELOPMENT	20.22		
BUILDINGS	19.93		
WASTE DISPOSAL	19.15		
OTHER COSTS	0.00		
TOTAL PROCESSING COSTS		342.21	
TOTAL CAPITAL COSTS			493.05

OPERATING COST SUMMARY

MINING SECTOR			
ENERGY	3.68		
LABOR	4.01		
MATERIALS	9.39		
FIXED CAPITAL CHARGES	2.96		
MISC. CHARGES	1.09		
TOTAL		21.14	
TRANSPORT SECTOR			
ENERGY	3.11		
LABOR	7.54		
MATERIALS	2.21		
FIXED CAPITAL CHARGES	1.36		
MISC. CHARGES	0.67		
TOTAL		14.89	
PROCESSING SECTOR			
ENERGY	19.26		
LABOR	23.76		
MATERIALS	12.76		
FIXED CAPITAL CHARGES	6.84		
MISC. CHARGES	1.90		
TOTAL		64.52	
TOTAL OPERATING COSTS			100.55

P AND E RESULTS

SIZE OF CLAIM:	26808.7	SQUARE KILOMETERS
PROSPECTING EXPENSE	1.6	
EXPLORATION EXPENSE	14.8	

NUMBER OF MINESHIPS:	1	NUMBER AND SIZE OF MAIN TRANSPORTS:	2 - 50
HOURLY RATE OF ORE RECOVERY PER SHIP:	562.5	NUMBER AND SIZE OF SMALL TRANSPORTS:	1. - 30
PIPE DIAMETER:	1.5		
SOLID FRACTION:	0.140		
POWER REQUIREMENT PER SHIP:	17055.5		
FORWARD VELOCITY (FEET PER SECOND):	5.9		

```
DEEP OCEAN MINING STUDY
RUN NUMBER  1 - 1

VALUES OF INPUT PARAMETERS:

FINANCIAL PARAMETERS

     TIME FACTORS:
        (YEARS)

  PROJECT STARTUP     : 1976
  EXPLORATION PERIOD  :    2
  R&D PERIOD          :    2
  INVESTMENT PERIOD   :    3
  OPERATING PERIOD    :   25
  TOTAL DELAYS        :    0
  PROJECT LIFE        :   30

     TECHNOLOGICAL FACTORS:

  NOMINAL ORE PRODUCTION/YR (MDST) :    3.00
  EXPLORATION EXPENSE ($MILLION)   :   14.84
  R&D EXPENSE         ($MILLION)   :   50.00
  CAPITAL INVESTMENT  ($MILLION)   :  493.05
  OPERATING EXPENSE/YR($MILLION)   :  100.55
  STARTUP EFFICIENCIES:
                   PRODUCTION      :  100.00%
                   COST            :  100.00%
  RECOVERY EFFICIENCIES:
                       NICKEL      :   95.00
                       COPPER      :   95.00
                       COBALT      :   60.00

     ECONOMIC FACTORS:

  AVERAGE ANNUAL INFLATION RATES:
     CAPITAL EQUIPMENT  : 0.0%
     OPERATING EXPENSES : 0.0%
     COMMODITY VALUES   : 0.0%
     DISCOUNT RATE      : 0.0%

        COMPOSITION:    COMMODITY VALUES:
  NI       1.50           $ 2.00
  CU       1.30           $ 0.71
  CO       0.24           $ 4.00

     FINANCIAL FACTORS:

  DEBT FUNDING               : 50.00%
  INTEREST RATE              : 10.00%
  LOAN PERIOD (YEARS)        : 10
  PROJECT DISCOUNT RATE      : *****
  DEPRECIATION METHOD
  (SOYD=1,DB/SL=2,SL=3,DE=4)
       MINING EQUIPMENT      : 2
       TRANSPORT EQUIPMENT   : 2
       PROCESS EQUIPMENT     : 2
  DEPRECIATION PERIOD (YRS)
       MINING EQUIPMENT      : 10
       TRANSPORT EQUIPMENT   : 18
       PROCESS EQUIPMENT     : 14
  PROJECT SALVAGE VALUE      : 0.00%

     POLICY FACTORS:

  TAX RATE               :  48.00%
  INVESTMENT CREDIT      :  10.00%
  DEPLETION ALLOWANCE    :  14.00%,14.00%,14.00%,
  VALUE OF LANDED ORE    : $ 0.00/TON
  SOCIAL DISCOUNT RATE   :  10.00%

                 OUTPUT SUMMARY

  PROJECT NPV (@******%)  : ******** ($1976 X 1MILLION)
  PROJECT IROR            :   18.14%
  SIMPLE PAYBACK          :     1986 ( 5.4 YEARS)
```

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	********	********	********	********	********	********	********	********	********	********
COMMODITY SALES(LBS X 1MILLION):										
NICKEL	0.00	0.00	0.00	0.00	0.00	85.50	85.50	85.50	85.50	85.50
COPPER	0.00	0.00	0.00	0.00	0.00	74.10	74.10	74.10	74.10	74.10
COBALT	0.00	0.00	0.00	0.00	0.00	8.64	8.64	8.64	8.64	8.64
COMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.00	0.00	0.00	0.00	0.00	171.00	171.00	171.00	171.00	171.00
COPPER	0.00	0.00	0.00	0.00	0.00	52.61	52.61	52.61	52.61	52.61
COBALT	0.00	0.00	0.00	0.00	0.00	34.56	34.56	34.56	34.56	34.56

--- OPERATING STATEMENTS ---

YEAR	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	********	********	********	********	********	********	********	********	********	********
GROSS REVENUES	0.00	0.00	0.00	0.00	0.00	258.17	258.17	258.17	258.17	258.17
COST OF GOODS SOLD	0.00	0.00	0.00	0.00	0.00	117.64	100.55	100.55	100.55	100.55
MARKET & GENL EXPENSE	0.00	0.00	0.00	0.00	0.00	7.75	7.75	7.75	7.75	7.75
R&D/P&E EXPENSE	25.80	25.80	7.42	7.42	0.00	0.00	0.00	0.00	0.00	0.00
GROSS PROFIT	-25.80	-25.80	-7.42	-7.42	0.00	132.79	149.88	149.88	149.88	149.88
DEPRECIATION	0.00	0.00	0.00	0.00	0.00	73.45	62.13	52.62	44.62	37.87
INCOME BEFORE INTEREST&TAX	-25.80	-25.80	-7.42	-7.42	0.00	59.34	87.75	97.26	105.26	112.01
INTEREST EXPENSE	0.00	0.00	8.22	16.44	24.65	24.65	23.11	21.40	19.53	17.47
INCOME BEFORE TAX&CREDITS	-25.80	-25.80	-15.64	-23.86	-24.65	34.69	64.64	75.85	85.73	94.53
DEPLETION ALLOWANCE	0.00	0.00	0.00	0.00	0.00	7.72	7.52	7.30	7.13	6.99
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	26.96	57.12	31.67	0.00	0.00
INCOME BEFORE TAX	-25.80	-25.80	-15.64	-23.66	-24.65	0.00	0.00	36.88	78.60	87.54
INVESTMENT CREDIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.85	18.86	8.19
TAX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.85	18.86	33.83
NET INCOME	-25.80	-25.80	-15.64	-23.86	-24.65	0.00	0.00	28.03	59.74	53.71

--- CASH FLOW SUMMARIES ---

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
NET INCOME	-25.80	-25.80	-15.64	-23.86	-24.65	0.00	0.00	28.03	59.74	53.71
DEPRECIATION EXPENSE	0.00	0.00	0.00	0.00	0.00	73.45	62.13	52.62	44.62	37.87
DEPLETION ALLOWANCE	0.00	0.00	0.00	0.00	0.00	7.72	7.52	7.30	7.13	6.99
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	26.96	57.12	31.67	0.00	0.00
ANNUAL INVESTMENT	0.00	0.00	82.17	82.17	82.17	15.47	17.02	18.72	20.59	22.65
CASH FLOW	-25.80	-25.80	-97.81	-106.03	-106.83	92.67	109.76	100.91	90.89	75.93
DEBT/EQUITY RATIO	0.00	0.00	1.00	1.00	1.00	0.88	0.77	0.66	0.55	0.45
PRESENT VALUE (******$)	********************									
NET PRESENT VALUE	********************									
CUMULATIVE NATIONAL BENEFIT	-25.80	-49.25	-130.09	-209.75	-282.72	-223.05	-159.16	-101.08	-48.28	-0.28
CUMULATIVE DISCOUNTED TAXES	0.00	0.00	0.00	0.00	0.00	2.12	4.06	10.36	20.75	36.55

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
	********	********	********	********	********	********	********	********	********	********
COMMODITY SALES(LBS X 1MILLION):										
NICKEL	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50
COPPER	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10
COBALT	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64
COMMODITY REVENUES($ X 1MILLION):										
NICKEL	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00
COPPER	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61
COBALT	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56

--- OPERATING STATEMENTS ---

YEAR	1986	1987	1989	1989	1990	1991	1992	1993	1994	1995
	********	********	********	********	********	********	********	********	********	********
GROSS REVENUES	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17
COST OF GOODS SOLD	100.55	100.55	100.55	100.55	100.55	100.55	100.55	100.55	100.55	100.55
MARKET & GENL EXPENSE	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75
R&D/P&E EXPENSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GROSS PROFIT	149.88	149.88	149.88	149.88	149.88	149.88	149.88	149.88	149.88	149.88
DEPRECIATION	32.23	28.81	25.87	25.57	25.30	19.03	19.03	19.03	19.03	2.12
INCOME BEFORE INTEREST&TAX	117.65	121.07	124.01	124.31	124.58	130.85	130.85	130.85	130.85	147.76
INTEREST EXPENSE	15.21	12.72	9.98	6.96	3.65	0.00	0.00	0.00	0.00	0.00
INCOME BEFORE TAX&CREDITS	102.44	108.35	114.04	117.35	120.93	130.85	130.85	130.85	130.85	147.76
DEPLETION ALLOWANCE	6.88	7.08	7.26	7.28	7.30	5.81	5.81	5.81	5.81	6.86
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INCOME BEFORE TAX	95.56	101.27	106.78	110.07	113.63	125.04	125.04	125.04	125.04	140.90
INVESTMENT CREDIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAX	45.87	48.61	51.25	52.83	54.54	60.02	60.02	60.02	60.02	67.63
NET INCOME	49.69	52.66	55.52	57.24	59.09	65.02	65.02	65.02	65.02	73.27

--- CASH FLOW SUMMARIES ---

NET INCOME	49.69	52.66	55.52	57.24	59.09	65.02	65.02	65.02	65.02	73.27
DEPRECIATION EXPENSE	32.23	28.81	25.87	25.57	25.30	19.03	19.03	19.03	19.03	2.12
DEPLETION ALLOWANCE	6.88	7.08	7.26	7.28	7.30	5.81	5.81	5.81	5.81	6.86
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANNUAL INVESTMENT	24.91	27.40	30.14	33.16	36.47	0.00	0.00	0.00	0.00	0.00
CASH FLOW	63.89	61.15	58.51	56.92	55.22	89.86	89.86	89.86	89.86	82.25
DEBT/EQUITY RATIO	0.35	0.25	0.16	0.08	0.00	0.00	0.00	0.00	0.00	0.00

PRESENT VALUE (*****%) **
NET PRESENT VALUE **

CUMULATIVE NATIONAL BENEFIT	43.35	83.02	119.08	151.87	181.67	213.37	251.74	282.07	309.64	334.71
CUMULATIVE DISCOUNTED TAXES	55.55	73.79	91.21	107.51	122.77	137.96	151.77	164.32	175.73	187.35

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	********	********	********	********	********	********	********	********	********	********
COMMODITY SALES(LBS X 1MILLION):										
NICKEL	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50
COPPER	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10
COBALT	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64	8.64
COMMODITY REVENUES($ / 1MILLION):										
NICKEL	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00	171.00
COPPER	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61	52.61
COBALT	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56

--- OPERATING STATEMENTS ---

YEAR	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	********	********	********	********	********	********	********	********	********	********
GROSS REVENUES	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17	258.17
COST OF GOODS SOLD	100.55	100.55	100.55	100.55	100.55	100.55	100.55	100.55	100.55	83.45
MARKET & GENL EXPENSE	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75	7.75
RED/E&E EXPENSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GROSS PROFIT	149.88	149.88	149.88	149.88	149.88	149.88	149.88	149.88	149.88	166.97
DEPRECIATION	2.12	2.12	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INCOME BEFORE INTEREST&TAX	147.76	147.76	147.76	149.88	149.88	149.88	149.88	149.88	149.88	166.97
INTEREST EXPENSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INCOME BEFORE TAX&CREDITS	147.76	147.76	147.76	149.88	149.88	149.88	149.88	149.88	149.88	166.97
DEPLETION ALLOWANCE	6.86	6.86	6.86	7.02	7.02	7.02	7.02	7.02	7.02	7.02
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INCOME BEFORE TAX	140.90	140.90	140.90	142.86	142.86	142.86	142.86	142.86	142.86	159.95
INVESTMENT CREDIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAX	67.63	67.63	67.63	68.57	68.57	68.57	68.57	68.57	68.57	76.78
NET INCOME	73.27	73.27	73.27	74.29	74.29	74.29	74.29	74.29	74.29	83.18

--- CASH FLOW SUMMARIES ---

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
NET INCOME	73.27	73.27	73.27	74.29	74.29	74.29	74.29	74.29	74.29	83.18
DEPRECIATION EXPENSE	2.12	2.12	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEPLETION ALLOWANCE	6.86	6.86	6.86	7.02	7.02	7.02	7.02	7.02	7.02	7.02
TAX LOSS CARRY-FORWARD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANNUAL INVESTMENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CASH FLOW	82.25	82.25	82.25	81.31	81.31	81.31	81.31	81.31	81.31	90.20
DEBT/EQUITY RATIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PRESENT VALUE (******%)	********	********	********	********	********	********	********	********	********	********
NET PRESENT VALUE	********	********	********	********	********	********	********	********	********	********
CUMULATIVE NATIONAL BENEFIT	357.49	378.21	397.04	414.16	429.73	443.88	456.74	468.43	479.06	489.80
CUMULATIVE DISCOUNTED TAXES	197.91	207.51	216.24	224.28	231.59	238.23	244.28	249.77	254.76	259.82

INTERNAL RATE OF RETURN 16.14%

SIMPLE PAYBACK OCCURS IN 5.4 YEARS AFTER STARTUP (1996)

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($1976 X 1MILLION)

(AT VARIOUS DISCOUNT RATES)

DISCOUNT RATES	24.00	22.00	20.00	18.00	16.00	14.00	12.00	10.00	8.00
	-58.73	-43.63	-23.89	2.06	36.43	82.39	144.60	229.99	349.07
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00