J.D. Nyhart
M.S. Triantafyllou

A Pioneer Deep Ocean Mining Venture

MIT Sea Grant College Program

Massachusetts Institute of Technology
Cambridge
Massachusetts 02139

MITSG 83-14
June 1983

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by

J.D. Nyhart
M.S. Triantafyllou

and

J. Averback, A. Bliek, B. Sklar,
M. Gillia, D. Kirkpatrick, J. Muggerridge,
R. Nakagawa, J. Newman, A. Will

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Report No.: MITSG 83-14

Index No.: NA 79-AA-D-0010
R/MO-2

February 1984

ACKNOWLEDGMENTS

Support for this project was provided through the MIT Sea Grant College Program, Grant NA 79-AA-D-00101, by the Marine Minerals Division of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce and the U.S. Department of State.

Related Reports

A Cost Model of Deep Ocean Mining and Associated Regulatory Issues. J.D. Nyhart, et al. MITSG 78-4. 240 pp. $10.00.

Toward Deep Ocean Mining in the Nineties. J.D. Nyhart, M.S. Triantafyllou, et al. MITSG 82-1. 31 pp. $4.00.

Copies of these reports are available through

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EXECUTIVE SUMMARY

I. SUMMARY OF EVENTS LEADING TO COMMERCIAL PRODUCTION

The M.I.T. - NOAA Deep Ocean Mining Model is a flexible tool meant primarily as a basis for comparing the economic outcomes of a deep ocean mining venture under differing sets of assumptions as to costs, timing, regulatory policies, etc. The user can very easily choose the assumptions desired for a particular analytic purpose and introduce them in the computer program. This flexibility is appropriate to the high degree of uncertainty attending the future industry. Although more becomes known, or at least increasingly certain, each year about the technology, its costs and capabilities, the regulatory structure and, perhaps, the international legal environment, uncertainty over an industry which is still in its developmental stage remains high.

In the midst of such uncertainty, modelers must identify the assumptions upon which they base their work. In this study, three kinds of assumptions are made explicit and introduced into the model. First, a basic narrative of likely events is provided. It has been worked out in collaboration with the NOAA Division of Marine Minerals and the consultants to that office, identified in Chapter I B of this report. Second, capital and operating costs have been estimated, drawing on different sources, identified in the text and appendices, including the NOAA consultants. In some cases, alternative costs or ranges have been provided in addition to the estimates of the project team and the consultants. Finally, assumptions necessary to the financial analysis made in the model are described.

Presented in the following paragraphs is a brief narrative summarizing a set of likely operating events of a hypothetical pioneer deep ocean manganese nodule mining project.

The events of concern are mainly those leading to full commercial production for the project. The operating entity is assumed to be a consortium of companies, working together initially in a contractual arrangement with the pre-production operations carried on by one company or by an organization formed for that purpose. The consortium is based in the United States, with processing facilities located in this study, for illustrative purposes, on the West Coast of the United States. The manganese nodules are recovered from a Pacific Ocean minesite located within a belt of ocean bottom south of the Hawaiian Islands, north of the Equator, between the Clarion and Clipperton fracture zones and extending almost to Mexico from 180 degrees west longitude. This area contains manganese nodules with comparatively high concentrations of nickel, copper and cobalt. These three metals are the primary marketable products of this project.

A project of this nature requires a vast amount of technical "know-how" and capital expenditure. The satisfaction of these requirements can be undertaken in three operational phases. The first phase involves the pre-production or "up-front" work;the second, the contract and construction operations, or investment phase, necessary for recovery of the target metals in marketable quantities;and the third phase, the commercial operations over a 20-25 year period.

A. Pre-Production Phase

The pre-production, or "up-front" phase, of the operation involves both the research and development (R&D) work aimed at assembling the technologies necessary to mine,transport, and process the manganese nodules, and the prospecting and exploration (P&E) work necessary for defining the quantity, quality, and location of the manganese nodules resource. The results of this work supply the information necessary to make a decision on whether or not commercial production is both technically and financially feasible.

B. Contract and Construction (Investment Phase)

The contract and construction phase of the operation begins when the decision is made to invest in the facilities and equipment required for a full-scale project. During this phase, the contracts are let and the construction of the major units of capital equipment is undertaken. At this point the consortium commits the capital required for building the necessary equipment and facilities, as defined and developed by the pre-production R&D activities, and there is no turning back.

C. Commercial Operations

The commercial operations phase of the projects begins when construction of the capital equipment for the mining, transportation, and processing activities is completed, and the start-up period ends, estimated between one and two years. During the start-up period the technology is further debugged and the system brought up to its full design production rate. The project operates at this design capacity through the remainder of its life (approximately 20-25 years) unless unforeseen slow-downs or shut-downs are encountered.

There are at least eight basic interdependent operations involved in the commercial operations phase of a deep ocean mining project. They are: 1) continuing R&D and exploration activities; 2) the mining operation and its supporting activities; 3) the transportation of ore from the minesite to the port terminal; 4) the operation of the ore discharge terminal; 5) the crew and supply vessel operation; 6) on-shore transportation to and from both the processing plant and the ore discharge terminal; 7) the nodule processing activities; and

8) the waste disposal operations. The activities, facilities and equipment required for successfully conducting these commercial operations of an ongoing ocean mining project are outlined in more detail in Section II - C. They are summarized here.

1. Continuing Preparations: Research and Development and Continuing Exploration

The R&D effort will continue in mining, transport, and processing as initial design flaws or gaps are rooted out and efficiency is improved. The data required for this redesign effort is generated, for the first time, from the actual commercial operation itself. Likely improvements are looked for in the mining system and navigation sub-systems, in the nodule slurry transport system, in metals recovery efficiency, and the debugging of long- and short-term problems which develop in processing during and after start-up.

During the mining operation, the continuing exploration effort provides the miner with a complete and accurate topographic and assay map of the site. Also, a mining plan is developed, keeping at least one year ahead of the mineship operation. Finally, low-level service from the assay lab is required on a continuing basis.

2. Mining

The at-sea mining operation involves the use of one or more specially designed mining vessels which employ hydraulic lifting techniques (submerged pumps) for recovering the manganese nodules from the ocean floor in about 18,000 feet of water at a rate of 3,000,000 dry tons (4,500,000 as mined tons) per year. The mineship is similar to a drillship, with a central moon pool, a gimballed and heave-compensated pipe suspension system, and pipe handling equipment. Provisions are made for the stowage of mined nodules which are periodically off-loaded at sea to a transport vessel. The mineship is dynamically positioned, using bow and stern thrusters, to enable it to follow a predetermined mining path. In addition to the mineship, there may also be a need for one or more smaller vessels to support the mineship at the minesite.

3. Marine Transport, Ore Discharge Terminal, On-Shore Transportation, and Marine Support Operations

The transportation operation requires equipment and facilities necessary for transporting nodules from the mineship(s) to the processing plant;crew and supplies from a port facility to the mineship;waste from the process plant to a disposal site; and supplies to and products from the processing plant. The transportation of nodules to the processing plant, assumed to be on the West Coast of the United States, requires a fleet of ore transport vessels, a dedicated port facility in a developed port on the U.S. West Coast near the processing plant, and a slurry pipeline system for transporting the nodules from the port facility to the process plant. Both the transport ships described above, and a high-speed supply vessel based at a second port facility located nearer the minesite (possibly in Hawaii) provide the mineship with fresh crew and supplies. This alternate port facility serves as a logistics based for the mineship(s) and its supporting vessels, and for the research vessel(s). A slurry pipeline system removes wastes from the plant to a land waste disposal site. If the wastes are to be disposed by ocean dumping, the nodule slurry pipeline is used to deliver wastes to the port facility. If an ocean outfall is used, a separate pipeline will run from the plant to another discharge point. Also provisions for roads and/or rail lines to transport personnel, supplies, and products to and from the various facilities mentioned above must be made where necessary.

4. Processing

The recovered nodules are processed using a reduction/ ammoniacal leach technique resulting in the recovery of nickel, copper and cobalt as marketable products. This recovery technique is modeled for illustrative purposes and does not necessarily reflect the exact system that any particular consortium might employ.

The processing plant is located on the West Coast of the United States to allow easy access to the anticipated minesite. The plant is sited in an area which can provide the electrical power, manpower, air and rail transportation, public roadway network and other such requirements necessary for a nodule processing facility. In addition, the process plant is built as close to the ore discharge port facility as economically and politically feasible.

5. Waste Disposal

This analysis assumes that the tailings waste are disposed of by using lined slurry ponds at a site removed from the processing plant. In reality, however, the waste disposal site configuration is highly dependent on the local topography, geology, and climate. The size and siting of this disposal site can vary with different waste handling options, such as decant ponds, decant pipelines and different degrees of waste pretreatment. The use of ocean dumping or an ocean outfall are other alternatives which might be considered.

II. TIMING

In this description of a hypothetical pioneer deep ocean mining venture, it is assumed that Phase 1 began in 1970, year 0 of the project timelines (figure 1 and 2), which summarize the overall timing of a venture. By 1981, the U.S. based consortia were understood to be at the point roughly corresponding to year 11 in the timelines. The time prior to year 10 is past history. The pre-mining P&E, bench test R&D, pilot miner construction and testing are completed, or nearly so, and the project evaluation preceding a major "go" decision is underway. At the outset of year 12, acquisition of equipment begins for at-sea endurance testing of a reasonably large-scale mining system. Approximately one-and-a-half years later, the testing begins. Six months into this testing, the at-sea mining operation has proved sufficiently successful to allow further investment in a demonstration-size processing plant to begin, requiring about a year for construction after state and local permits are obtained. During the demonstration plant construction period, the miner is still at-sea finishing the endurance testing and developing the 100,000 ton nodule stockpile required for the demonstration plant test run. At the end of the demonstration plant construction period (year 15), the plant begins operations. A year of operating the demonstration plant should be sufficient to provide enough product and enough data to make the final "go/no-go" decision for commercial production. However, the demonstration plant will run for an additional year after the "go" decision to accumulate more data.

If the final "go/no-go" decision is favorable, the project enters the Investment and Construction phase in year 16. The design, contract and/or procure, build, and test periods for the at-sea components of the project requires five-and-one-half years as explained in Section II-B. After about one year of design work, orders are placed for major equipment. Plant construction itself cannot begin until state and local permits have been obtained, about year 19.

The Commercial Production period begins halfway into year 21 with start-up lasting one-and-a-half years for both mining and processing. Thus, at the beginning of year 23, full production begins and runs for about 20-25 more years.

III. SUMMARY OF COST ESTIMATES BY SECTORS

The model of the project contains a cost estimation section and a financial analysis section/ The former divides the capital and operating cost estimates into ten sectors as indicated in Table ES-1.

TABLE ES-1

SUMMARY OF CAPITAL AND ANNUAL OPERATING COSTS BY SECTORS

	Capital Costs (In Millions $)	Annual Operating Costs (In Millions $)
Sector 1: Preparatory Prospespecting and Exploration and Research and Development	Capitalized	Expensed
	30.00	142.0
TOTAL		172.0
	Capital Costs (In Millions $)	Annual Operating Costs (In Millions $)
Sector 2: Mining	306.24	65.58
Sector 3: Transport	200.88	22.20
Sector 4: Ore Discharge Terminal	22.87	3.19
Sector 5: Onshore Transportation	36.65[1]	7.68
Sector 6: Processing	449.10	99.60
Sector 7: Waste Disposal	15.28[2]	3.90[3]
Sector 8: Marine Support	1.80	4.88
Sector 9: General and Administrative	88.20	4.00
Sector 10: Continuing Preparations	.0	6.00
TOTAL	1,121.02	217.03

1. Slurry pipeline: capital cost 10.89
   land .40
   Water slurry pipeline: cap. cost 22.40
   land .96
   Roads and railroads 2.00
   36.65

2. Capital cost: 12.03
   Land 3.25

3. First and second year: 0.60
   All subsequent years except last 3.90

IV. SUMMARY OF FINANCIAL ANALYSIS

The second major section of the model is the financial analysis section. In this section, the estimated costs and revenues of the venture are integrated with various taxation and regulatory assumptions to calculate the financial return of the project. The model projects the annual net cash flow of the venture using the previously estimated costs in combination with assumed ore assay, recovery, and lifting rates, and assumptions regarding the economic environment.

These cash flows are then used in the determination of three measures of profitability -- adjusted net present value, internal rate of return, and simple payback. Alternate "upside" and "downside" analyses are also made, as are several sensitivity analyses.

The real-term, non-inflated internal rate of return for the baseline set of assumptions, with U.S. taxation and assuming 50% debt funding, is 9.21%. Comparable figures for upside and downside sets of assumptions are 21.96% and -6% respectively.

CHAPTER I. THE STUDY

A. Changes From the 1978 MIT Study

This study is a sequel to and revision of an earlier work by a team at M.I.T. providing an initial estimate of costs of a hypothetical deep ocean mining venture[1]. Since 1975-76, when most of the data were gathered for the original cost estimations, much more has been learned about the technical, political, and legal prospects for deep ocean mining. This study reflects data that have become available from industry sources, from the results of U.S. government research contracts, from consideration of U.S. legislation on deep ocean mining, and from negotiations at the Law of the Sea Conference.

The new study is distinguished in several additional ways from that published in 1978[2]. The consideration given the projected engineering requirements of the mining, transportation, processing, and waste disposal sectors is at a deeper level of detail than previously[3]. In particular, the sizing analyses underlying the cost estimates in Chapter II of the mining and transportation sectors provides additional confirmation of the assumptions made in the model[4]. The analysis of possible economic return accruing to a pioneer venture has been expanded by adding examination of alternate sets of assumptions developed by changing several of the critical variables and by extended sensitivity analyses of those variables in Chapter IV. And several technical improvements in the computational aspects of the model have been made to provide new flexibility in its use and a greater degree of accuracy in calculating the cash flow as developed in Chapter III. The latter includes changes based on a tax accountant's review of the tax calculations[5].

B. Uncertainty Surrounding Deep Ocean Mining Costs and Timing

Although much has been learned and many facts and perspectives have come into the public domain in the last few years, it remains as true as it was in 1978 that there is no actual commercial experience in deep ocean mining from which cost estimates and projections can be made. Much uncertainty still surrounds this new evolving technology. These cost estimates reflect that uncertainty. They have been evolved to a greater level of detail throughout and, as indicated above, have much more industrial sector input than before. Yet the fact of the matter is that no one knows with confidence what a deep ocean mining project will cost.

This study is, therefore, vulnerable. It is the project team's belief that in many cases there are feasible alternatives to the facts which premise this study. Ideally all facts would have been spelled out, laid parallel to the estimates used here, and analysed in detail. Constraints of time and budget prevented such an examination. Instead, an adaptation of the base-case, best-case, worst-case technique used in investment analysis is made, as are sensitivity analyses of several significant cost assumptions.

A second major source of uncertainty is the timing of events for the deep ocean mining industry. It is likely that deep ocean mining will take place. The pace at which development proceeds, however, depends upon managers' estimates of trends in future metal prices;the speed with which technological problems in developing systems for commercial mining schedules can be overcome;and the staisfactory resolution of international law issues and political questions over exploitation and ownership of the seabed, most notably in the Third United Nations Conference on Law of the Sea.

The M.I.T. - NOAA model allows subsequent users great flexibility in changing the assumptions of cost and timing at its core. This structure facilitates answering both "what if" questions and changes in the baseline assumptions used as new data and experience become available.

C. Layout of the Study

Chapter II sets out the assumptions as described above, and the associated cost estimates on a sector-by-sector basis, using the basic ten - sector division into which the whole project is divided. Little detail is provided and cost estimations are summed only at the subsector level. For most sectors, further detail is provided in appendices. Here, typically, costs are identified at the sub-subsector level, or the component units are named so that readers may have an idea of what went into the cost considerations. In three cases where the project team felt that experience with the technology to date was particularly sketchy or for which numerous solutions have been proposed in the literature, the appendices indicate the nature of sizing analyses that were done. From these, size and power requirements were identified prior to elaborating cost estimates.

Chapter III provides a description of the financial analysis model. This description includes the specific assumptions given individual parameters and no corresponding appendix is needed.

Chapter IV provides the economic analysis of the projected return on the hypothetical investment as described in Chapter II, as well as analyses of alternative sets of assumptions. There is also an extensive sensitivity analysis made of the impact on return of several critical changes in individual assumptions in the model. This chapter is based on work done in completion of a Masters thesis at the Sloan School in May, 1981.[6]

II. DESCRIPTION OF EVENTS ASSUMED IN A HYPOTHETICAL PIONEER VENTURE AND SUMMARY OF THE MODEL'S COST ASSUMPTIONS

A. Preproduction Phase

1. Description of Assumed Events

Each consortium participant considering ocean mining as a feasible project probably has a "long range planning" capability in a company officer, a committee of the Board of Directors, or a consultant to the Chairman of the Board and/or the Chief Executive Officer. This capability decides how, if at all, the project will proceed and allocates funds for the prospecting and exploration (P&E) and research and development (R&D) efforts. Both the R&D and P&E efforts are divided into successive steps, each of which is funded based on the results of the previous steps. These intermittent "go/no-go" decisions (referred to as "GO1," "GO2," etc.) encountered at the end of one step prior to the funding and commencement of the next can be considered as "off-ramps." If the project evaluation at the end of each stage proves the project worthy of further investigation, the planners allocate funding, probably at an increased level, for the next stages of work. If the project does not appear favorable, the planners could decide to take the "off-ramp," thus resulting in shelving (a delay) or termination of the project. The P&E and R&D work conducted during the "upfront" phase of the project establishes a bank of knowledge upon which the consortium bases the ultimate decision whether to invest, and hence go into commercial production. This ultimate decision is referred to in this text as the final "go/no-go" decision. For this analysis, the project is assumed to pass the tests of technical success and economic viability at each decision point.

a) Pre-Commercial - Mining Prospecting and Exploration

Prospecting and exploration activities are carried out in two phases. During the first, or pre-commercial - mining phase, the miner delineates a minesite based on ore abundance, ore grade, soil characteristics, and topography. The second phase, called continuing P&E, comes immediately prior to and during commercial recovery operations. In it, the miner conducts a second round of bottom mapping, similar to but more intensive than that of the first phase. This second, continuing P&E is discussed further in Section II - C.

Pre-commercial-mining P&E is made up of the following three stages:

i) Background Work. This work includes the literature search to identify equipment, techniques, and general geological regions of high potential which are worth investigating further. Testing and perfecting equipment and techniques to be used during the P&E phase also takes place. Background work requires about a year.

ii) Prospecting. In prospecting, the aim is to identify potential minesites of commercial quality. First, a rough grid search of a large area is made. As an illustration, one firm's experience suggests that an area of approximately 400,000 square nautical miles be sampled, using free-fall grabs and still photographs.[1] Next, a medium grid search is made, narrowing the sections for future surveying. Here, the above experience suggests an area of approximately 126,000 square nautical miles be sampled using free - fall grabs and still photographs, and possibily a dredge to collect bulk samples on promising sections. Finally, a fine grid search is made to determine the area to be investigated during the exploration stages. An area of approximately 27,000 square nautical miles is sampled with free-fall grabs, still photos, a dredge allowing bulk samples to be used for chemical analysis, and spade or box cores. These activities can be completed in as few as two years.

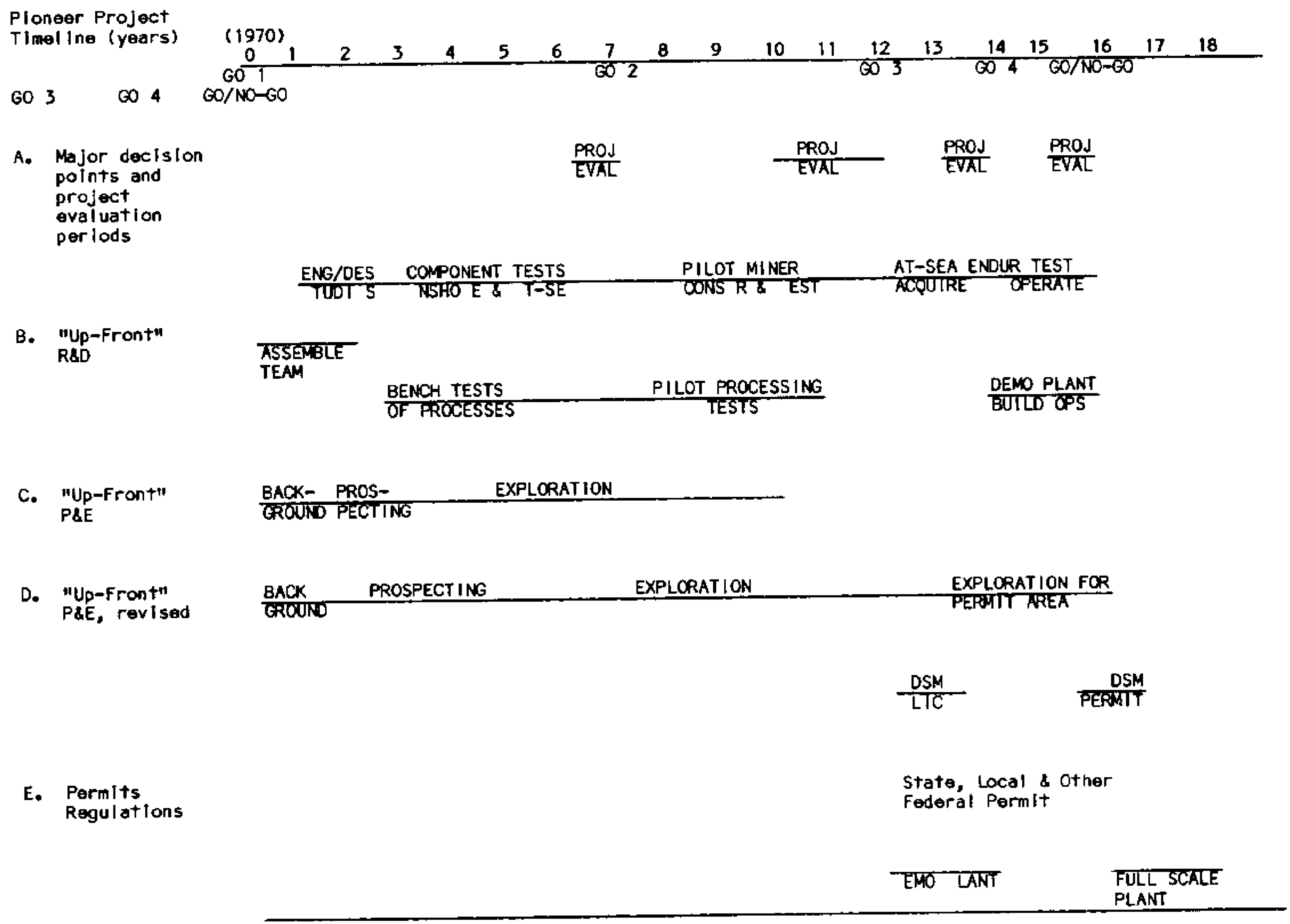
iii) Exploration. The purposes of exploration are to delineate the ore deposits, determine concentration and abundance of nodules, obtain soil mechanics data, and map the potential minesite selected through the prospecting process. The minesite is searched with photographs and seismic surveys and sampled extensively. As an illustration, an area of approximately 8,000 square nautical miles is surveyed using the same techniques as before. Bathymetric seismic measurements are also made.

The selected minesite must be topographically mapped, using side-scan sonar and television, to determine the miner's initial path. At this stage, the entire area may not be covered. The degree of coverage depends on how much continuing exploration is anticipated during the commercial production phase. Vessel speed is estimated at 2.8 kilometers per hour when mapping and 8 kilometers per hour when not mapping, with a time-weighted average speed of 3.8 kilometers per hour. Sampling is continued for additional ore concentration information.

During exploration, a mining operation plan is established. The mining plan must be sufficiently developed so that mining operations start when exploration is completed. Costs during this P&E period include vessel charter rates, research team salaries, and navigation, sampling, and survey-

FIGURE II-1 A, B, C, D, E:

TIMING OF "UP-FRONT" PHASE FOR A PIONEER PROJECT



ing equipment.

It is estimated that these activities require approximately seven years if carried out without delay.

iv) Timing of Prospecting and Exploration Stages. In this study, the chronology of the events described above, including creation of the U.S.-based consortia starts about 1970, with one year's background work. The pre-commercial-mining events shown in Figures II-1B, II-1C, and II-1D depict the subsequent P&E (as well as R&D) activities, with year 11 representing the situation at the time of writing, i.e., 1981. The consortia are approaching the end of their pre-commercial-mining phases, with critical R&D at-sea endurance and demonstration work remaining before a final go/no-go decision is taken.

Their experience as "living history" is demonstrated by comparison of Figures II-1E and II-1D. Figure II-1C was developed during early 1980, and took the perspective of a mining project manager at the outset, e.g., year 1, assuming also that interim U.S. legislation had then been enacted.[2] Figure II-1D shows the more realistic situation existing after U.S. legislation was actually passed in mid - 1980, adjusted to show pre-commercial-mining being carried out to the period just prior to application for the permit required by new U.S. legislation, i.e., by year 15. Figure II-1D also reflects delays in R&D and the impact of industry evaluations of the economic, political, and international legal climate. (See below.) The net effect is that the continuum of P&E activity is likely to stretch over 15 rather than 10 years as projected in Figure II-1C though at a diminished level of annual activity. Still later, substantial uncertainties as to the economic return and the international legal status of deep ocean mining have been reflected, in the United States, in further delay in carrying out the hypothetical timetable described here.

b) Pre-Commercial-Mining Research and Development.

The research and development work is carried out in two phases. The first, pre-commercial-mining R&D, develops the major equipment. In the second, continuing R&D, activity runs concurrently with commercial production. (Continuing R&D is discussed further in Chapter II - C.)

Pre- commercial-mining R&D is further sub-divided into two stages. In the initial stage, the current technical status of ocean mining and the potential for future financial returns are ascertained through literature and patent searches; interviews; estimation of future metals prices and returns; and, small-scale bench tests of potential processing, transport, and mining systems. Using this information, an initial marketing strategy and business plan are developed. The marketing strategy defines which combination of metals and their respective recovery rates will be sought by the consortium. These in turn influence the choice of mining and processing technologies. Thus, in determining a marketing strategy, trade-offs between metal market and technical considerations must be made. The business plan delineates a detailed program, schedule, and budget for the next, or major, R&D effort and sets forth a tentative plan for commercialization activities, including capital funding. The business plan is dynamic and evolves as more knowledge is gained through R&D activities.

The bulk of the R&D funds is spent in this major R&D effort. The final contract plans for the components and systems are completed. The systems are taken through tests of increasing size. Simultaneously, more and better market and investment return analyses are made.

In processing R&D, both a pilot plant and a demonstration plant must be designed, built, and operated. The pilot plant is about a 1/10,000 scale operation whose key objectives include: the demonstration of the process of an integrated plant; the acquisition of preliminary design data for key operations; the determination of materials consumption, product yields, and product purities; and process revisions/optimization studies as required. In addition, the pilot plant provides information for cost estimates for both demonstration and commercial plants. The demonstration plant is about a 1/20 scale, "green field operation." From the demonstration plant comes the final design data for the commercial processing plant. It may also be beneficial to determine the commercial plant siting requirements at this step, since the closer the demonstration plant is sited to the commercial plant, the better.

Transport R&D deals with the unique problems created in handling and transporting large quantities of nodules, either from vessel-to-vessel or from vessel-to-shore. This effort requires the design of sophisticated slurry transport and ship control systems.

The mining R&D effort deals with the problems of collecting and lifting the nodules, and navigation while carrying out these activities. This requires at-sea testing of systems and components.

Research and development expenditures progress in stages, as described previously, and here are a substantial part of the overall capital requirements of the project. The greatest portion of funding is required for the capital - intensive pilot and demonstration processing plant tests and the mining system demonstration-scale test.

i) Timing. The beginning of the initial pre-mining R&D step is signified by the first "go" decision (GO1) as shown in Figure 1. This "go" decision allocates funds for the preliminary R&D work. As in the case of P&E, this work has started during 1970, the initial year of the project. This initial effort is conducted at low levels over a seven-year period (see Figures II-1 A and 1 B). Following this period, and assuming some technical success, a second "go" decision is made in year 7. One consideration evaluated before this "go" decision may be the need to secure additional financial participants in the venture. This "go" decision signals the beginning of major R&D activities for the project.

The first activities are the design, development and initial testing of the pilot mining system at sea and the pilot processing plant on land. These take up to five or five-and-a-half years. At the time of writing, mid-1981, the consortia are near the end of this pilot period, and have already completed most of their pilot work.

A third "go " decision point is reached before at-sea endurance testing begins and is projected for the beginning of year 12. It marks the beginning of the most expensive R&D work. The project evaluation period preceding it is rather long, because of higher expected costs of the endurance tests and demonstration scale processing plant (which follow), economic uncertainties, and uncertainties surrounding the Law of the Sea negotiations. The actual year of this decision point depends heavily on such factors.

Once a "go" decision is taken, timing is governed in part by the interaction of the mining and processing systems development activities. The degree of success of the at-sea endurance testing program determines whether the commitment is made to allocate the large expenditures required to construct a demonstration scale processing plant. In addition, the actual construction of the demonstration plant is contingent upon the ability to secure state and local building permits. Thus, project scheduling becomes dependent upon success with both the mining system and the permitting process.

The demonstration plant permitting activities are assumed to require two years. However, the length of this permitting period can vary significantly among different state and local jurisdictional areas. The building permits must be in-hand when construction begins and thus, the demonstration plant permitting period precedes the decision to begin construction. The timing of the demonstration plant permitting period is illustrated in Figure II-1E.

For this analysis, it is assumed that by the sixth monthof at-sea endurance testing the required demonstration plant permits are in-hand and sufficient technical success with the mining system allows construction of the demonstration scale processing plant to begin. At this point,a fourth "go" decision, to build the demonstration plant, is shown, reflecting the possibility that consortia management are using short planning horizons in light of the uncertainties. A tightly scheduled one-year construction period is shown on the assumption that not all demonstration plant subsystems must be in place for testing to begin. During the demonstration plant construction period, at-sea endurance testing and consequent nodule stockpiling activities continue with the aim of further debugging the mining equipment, while collecting enough nodules (100,000 tons) for the demonstration plant runs. With completion of the demonstration plant at the beginning of year 15, operation commences. This run is assumed to last for two years.

Halfway through this period, at the beginning of year 16, the decision on whether or not to invest in a commercial-size project is made, based on all information gathered, with special emphasis on the results of the demonstration plant runs and mining system tests. This decision is referred to as the final "go/no-go" decision (see project timeline, Figure II-1A). The extra year of demonstration plant operation after the final "go" is used to provide additional data for the design and operation of the full-scale plant.

ii) Impact of U.S. Federal Law on Timing. It is assumed that the mining consortium is United States based and therefore subject to the U.S. Deep Seabed Hard Minerals Resource Act (P.L. 96-283), which regulates deep seabed mining. The Act requires a U.S. deep ocean miner to obtain a Deep Sea Mining (DSM) License before exploration and a Deep Sea Mining Permit before commercial recovery. Existing, i.e., pioneer, consortia are exempt from the prohibition against exploration before receiving a license, so long as they make timely application. The DSM license and permit processing periods will require one-and-a-half and two years, respectively. (Both periods will run concurrently with R&D and P&E activities.) The license will thus be issued in mid-year 13, and halfway through year 15, application will be made for a DSM permit. The consortium should therefore have a DSM permit in-hand one year after the "go/no-go" decision.

2. Cost Estimates

Preparatory costs associated with the pre-production phase are categorized into five sectors in the model. The following table presents the sectors and the central values assumed in the model's base case.

TABLE II-1

PREPARATORY COSTS
(In Millions of U.S. $)

Sector 1	Pre-Commercial-Mining P&E	
	Prospecting	5.00
	Exploration	25.00
Sector 2	Pre-Commercial-Mining R&D	
	Mining Sector Related	60.00
	Transport Sector Related	6.00
	Processing Sector Related	70.00
Sector 3	Project Evaluation	0.00
Sector 4	Licenses, Permits, Payments to International Authority	0.00
Sector 5	General & Administrative	
	Management	4.00
	Sponsored Research	2.00
	TOTAL	172.00

For the base set of assumptions, the $ 172 million in preparatory costs are allocated in the following manner:

1. Of the combined R&D ($136m) and G&A ($6m) costs of $142 million, 15% are expended between GO1 and GO2, 30% between GO2 and GO3, and 55% between GO3 and GO/NO-GO. Within each of these three periods, costs are spread evenly over the appropriate years.

2. The prospecting costs ($5m) are spread evenly over the years of the years of the prospecting period.

3. The exploration costs ($25m) are spread evenly over the years of the exploration period.

Pre-production phase costs may be expensed, capitalized, or both, depending on their nature, when they occur, the state of the project's revenue stream, and the desires of the consortium members. Most frequently, corporations will choose to expense these preparatory costs if allowed under tax laws.

In the initial set of assumptions, R&D, project feasibility, permitting, and up-front general and administrative expenditures are all expenses.

Prospecting and exploration expenditures are expensed if the deposit is considered as U.S. based. If they are considered as foreign based, they may be capitalized. Although U.S. law is not entirely clear on this point, the assumption is made initially that the deposit is foreign based and therefore the P&E costs are capitalized.

B. Contract and Construction (Investment) Phase

1. Description of Assumed Events

During the second stage of R&D, prior to the "go" decision for commitment to a fully commercial project, the type, size, and quantity of equipment required for the project is identified and design specifications developed. This work includes the preparation of contract plans and specifications for the mining, transportation, and processing equipment and systems. In addition, during the period just prior to the final "go/no-go" decision, outside sources of design assistance for the various systems and sub-systems are identified.

Before the actual construction of any land-based facilities can begin, state and local permits for the construction of these facilities must be obtained. From recent studies sponsored by NOAA, the time required to secure these permits could be between four and seven years. Some of the initial, low cost work required to prepare the permits can be conducted during the R&D period, prior to the final "go/no-go" decision. Some permitting activities as well as work which is dependent on data resulting from runs of the demonstration plant, however, will have to be conducted after the final "go/no-go" decision and before ground is broken for the processing plant and other land-based facilities. For the purpose of this analysis an average permitting time of five-and-a-half-years is assumed. The first two-and-a-half years of this period occur during the R&D period with the remaining three years coming after the final "go/no-go" decision (See Figure II-2). As with the demonstration plant permitting period, the length of this permitting period can also vary significantly among different state and local jurisdictional areas.

The contract and construction phase of a deep ocean mining project, also known as the investment phase, is composed of at least four discrete activities. These activities include the final state and local permitting activities, the final or detailed design work using outside technical expertise, the contract and procurement activities, and the actual construction. In addition, there may also be a testing program initiated upon completion of the building activities.

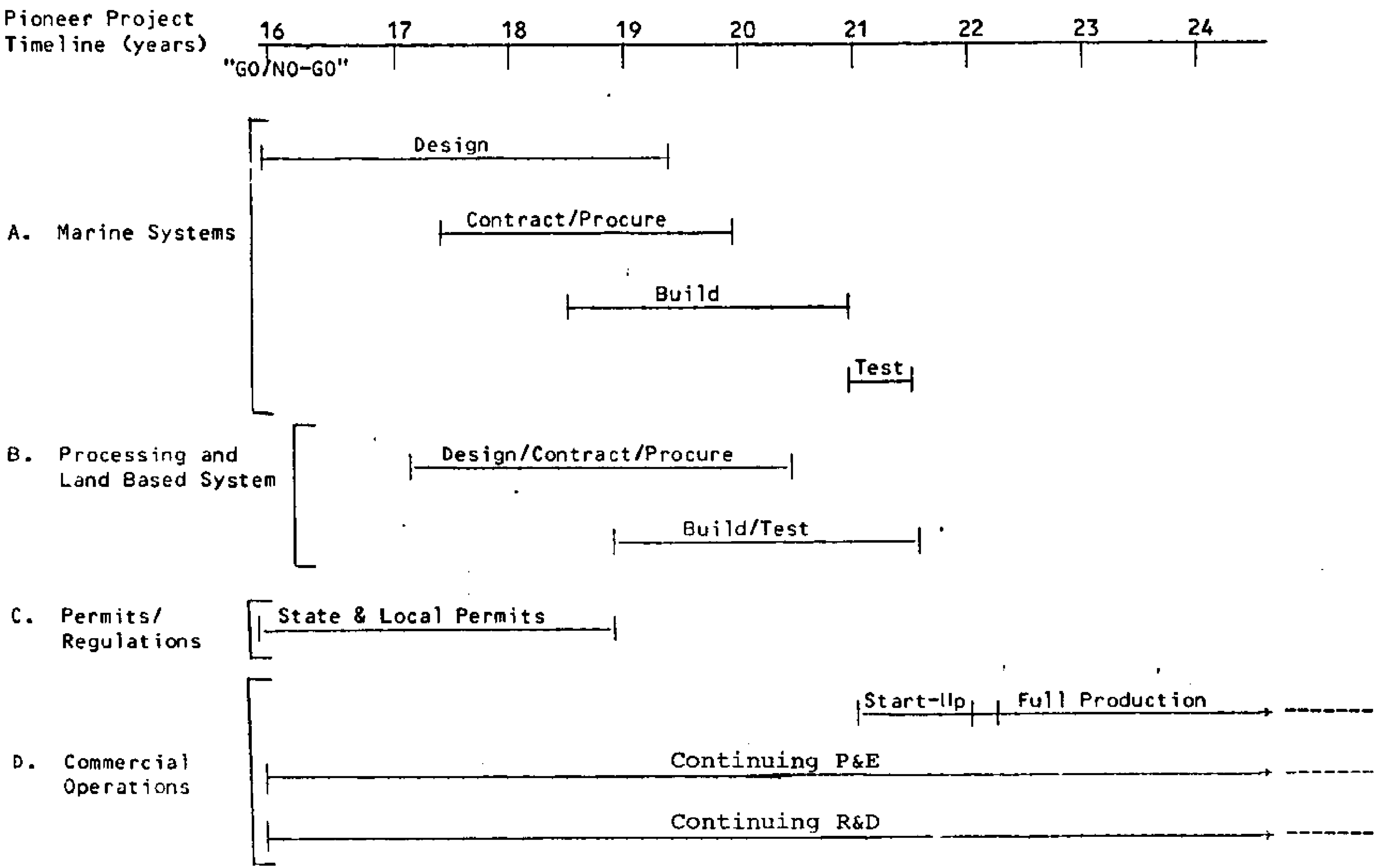
With the final "go" decision, the various systems design efforts begin. This work concentrates on confirming and correcting contract specifications, developing subsystems to permit their separate acquisitions, refining cost estimates, and providing professional technical support. Consortium R&D personnel with a complete understanding of the various R&D efforts supervise and integrate these design efforts.

The contract and procurement activities begin either immediately upon the completion of the final detailed design work, or prior to its completion for long lead-time items such as the ships, dredge pipe, and collector. These long lead-time items can be contracted via the letter-of-intent, preliminary contract, final contract and contract settlement route, thus striving for near optimum design and fabrication quality while maintaining financial fairness.

With the completion, or at least partial completion, of the contract and procurement activities, the building begins. It is during this period of building that the most significant expenditure for the major capital cost systems is made.

The timing of these allocations may vary from sector to sector. Figure II-2 gives an indication of the length of the contract and construction phase of the project for a pioneer venture. In addition, Figure 2 shows a breakdown

FIGURE II-2 A, B, C, D:
Timing of "Contract and Construction"
and "Commercial Operations" Phases



of the contract and construction phase into time periods for both the marine systems (mineships and transport vessels) and for the land-based facilities (processing plant, pipelines, port facilities, and waste site).

Figure II-2 shows that the mining system and transport vessel's contract and construction phase is assumed to require approximately five-and-one-half-years. The first years of this phase are dedicated to the final design and permitting efforts, with the exception of the contract and procurement of the long lead-time components of the marine system (ships, dredge pipe, collector) which start one-and-a-half-years into this phase, during year 17. This final design effort continues through year 18, with extensions into year 19 for the dredge pipeline and collector systems. The contract and procurement activities, with the exception of those mentioned above, begin in year 17 and proceeds through the end of year 19. Much of the actual building begins two-and-one-half-years into this phase and continues through the end of year 20. A six-month testing period begins at the outset of year 21 of the project timeline. This testing period allows for correcting deficiencies in the various systems, commissioning the vessels, and breaking in the equipment and personnel prior to the start-up operations.

The contract and construction phase for the commercial processing plant begins a year after the "go/no-go" decision and finishes four-and-a-half-years later in synchronization with the marine systems contract and construction phase. The detailed design effort and the contract and procurement activities start immediately with the onset of the processing plant contract and construction phase. These activities are scheduled at varying intensities through the first three to

TABLE II-2: INVESTMENT PERIOD EXPENDITURES
(Amounts in thousands of 1980 dollars)

Funding Requirements	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total
I. Capitalized Items:							
Sector 2. Mining	6,970	10,390	39,490	62,350	103,910	83,130	306,240
Sector 3. Ore Transportation	-	-	-	40,480	102,620	57,780	200,880
Sector 4. Marine Terminal	-	4,110	6,250	6,250	6,250	-	22,870
Sector 5. Onshore Transportation	4,340	-	5,350	12,470	10,800	3,690	36,650
Sector 6. Processing	-	39,210	107,820	127,420	117,610	57,040	449,100
Sector 7. Waste Disposal	-	-	-	670	9,380	5,230	15,280
Sector 8. Support/Services	-	-	-	-	-	1,800	1,800
Sector 9. General & Adminstrative							
-- Headquarters	4,000	4,000	4,000	4,000	4,000	4,000	22,000
-- Regulatory Compliance	-	-	-	-	-	-	-
-- Testing	-	-	-	-	-	66,200	66,200
SUB TOTAL	15,310	57,710	162,910	253,640	354,570	276,870	1,121,020
II. Expensed Items:							
Sector 10. Continuing Preparation	6,000	6,000	6,000	6,000	6,000	6,000	36,000
SUB TOTAL	6,000	6,000	6,000	6,000	6,000	6,000	36,000
GRAND TOTAL	21,310	63,710	168,910	259,640	360,570	282,870	1,157,020

Headquarters lease of only 1/2 year is applied during year 6 due to 1/2 year investment production overlap three-and-half-years of this phase. The actual construction begins two years into this phase and is completed two-and-one-half-years later at the end of the contract and construction phase. It should also be noted that the land transportation items (slurry pipelines, rail spurs, roads), the port facility, and the waste disposal site can be considered to follow a contract and construction phase scheduled similar to that described above for the processing plant. (See Figure II-2.)

2. Investment Phase Outlays

Investment period expenditures are summarized in Table II - 2. The contract and construction phase includes the major capital expenditures for all those sectors of the project involving capital equipment, i.e., Mining (Sector 2), Marine Transport (Sector 3), Ore Discharge Terminal (Sector 4), Onshore Transportation (Sector 5), Processing (Sector 6), Waste Disposal (Sector 7), Marine Support (Sector 8), and Continuing Preparations (Sector 10). The nature, volume and timing of these investments comprise the subject matter of Sectors 2 through 8, discussed in Sections II D - J. Continuing preparations are discussed immediately below, while general administrative expenses are reported in section II K.

C. Commercial Production Phase -- Continuing Preparation (Sector 10)

1. Description of Assumed Events

During the mining operation, a complete and accurate topographic mapping must be accomplished using sidescan sonar, television, etc. In addition, a sea floor transponder network must be deployed at a pace about one year ahead of the mineship. This transponder network will allow the mineship to position itself properly while mining. The objectives of this work, termed "Minesite Planning," are to:

-- Complete the topographic mapping of the year's mining area;
-- Complete development of the mining plan at a pace one to two years ahead of the miner; and
-- Prospect for future minesites.

This operation is active throughout the life of the minesite, although not necessarily in the form of an at-sea prospecting vessel. The activity will require 150 days per year of the research vessel. However, there will be some activity either on land or at sea all the time, and thus require a full year's use of the research team.

The continuing R&D effort is a minor, but necessary, operation whose function is to aid in improving the mining, transport, and processing technologies. Little more can be said for this operation, except that its cost will be comparatively low, with an allotted operating budget of about 1% of projected full - production sales of metals.

2. Cost Estimates

The model assumes $ 4 M per year of continuing P&E costs and $ 2 M per year of continuing R&D. Costs thus total $ 36 M for the investment period. According to present tax law, it appears that these expenditures are developmental, and may therefore be expensed. During the production phase, continuing preparations are also allowed as developmental.

D. Mining (Sector 2)

1. Description of Assumed Events

The aim of the at-sea mining operation is to recover 3,000,000 dry short tons per year of manganese nodules from the ocean floor at depths of up to 18,000 feet. To accomplish this, at least one, and probably two, specially constructed mining vessels will be required to collect the 4,500,000 tons of wet nodules. Use of two vessels also prevents a total shutdown should one vessel be disabled. The number of mineships employed is based on both engineering and financial criteria. The engineering criteria are a function of the maximum speed and nodule collection rates practical for a mining operation. The financial criteria concern the trade-off between the lower mineship and transport vessel costs of a one - miner system and the back - up capabilities of a multiple mine-ship operation. If engineering analyses show that a single miner operation is feasible, a financial analysis must then evaluate the relative cost of the catastrophic loss of a one-miner mineship operation versus a multiple miner operation.

The major capital items associated with the mining system are the mining vessels. For this statement of projected events, it is assumed that the mineships are U.S. built vessels, whose design configuration is a combination of an ore carrier and a conventional drill ship. The vessel must stow large quantities of nodules, in addition to supporting significant amounts of mining machinery and crew facilities. There must also be space for stowing spare parts, fuel oil and food. Special features, similar to those found on various drill ships, include a sizeable (41' by 74') moonpool, through which the mining pipestring will be suspended, a large (150') motion-compensated derrick with associated drawworks for supporting the pipe-string, racks for pipe storage, and dynamic positioning equipment for keeping the vessel on course while mining.

The ocean mining operation itself removes the manganese nodules from the ocean floor and lifts these nodules to the surface. The operations will use a towed bottom collector unit equipped with steering capability and a hydraulic lifting system, respectively. The collector unit is responsible for gathering the nodules, sorting out the ones that are too large for the selected pipe diameter, and feeding the acceptable ones to the life system for transportation to the surface. The system proposed to convey the nodules to the surface is a fluid (hydraulic) lift system that mixes nodules in a slurry with sea water and pumps the mixture to the surface through a vertical pipe-string (dredge pipe). There are basically two designs that may be considered for the first generation lift system: conventional slurry pumps and an airlift system. The slurry pump system uses submerged, multi-stage centrifugal pumps to lift the mixture to the surface, while the airlift system injects air into the slurry, so that a three-phase mixture of air, nodules, and water is lifted to the surface.

A breakdown of equipment necessary for the mining operation is presented in Appendix 2. The plan providesfor one or two cranes aboard the miner to handle the fuel and nodules umbilical. The floating fuel and nodules umbilical facilitates at-sea transfer operations. A motion-compensated pipe suspension tower with adjacent pipe rack and skidway are necessary with deck - mounted reels for handling the power cable adjacent to the pipe suspension tower. A small, very seaworthy launch should be available for picking up air-drop bundles as well as handling lines, clean-up gear, and man-overboard duties.

The nodule pumping system subsector takes into consideration the following items: pumps or air compressors for supplying the lift power to raise the nodules;power cable and related connectors for the submerged pump system to provide power to the pumping unit and to the collector unit. If the airlift system is employed, the power cable is still needed, but can be much smaller due to the lower sub-surface power requirements. Provisions must also be made for dump and diffusion valves, in situ instrumentation, and topside controls for the lift systems.

The dredge pipeline system requires individual pipe sections of the lift (dredge) pipestring whose length can be selected based on the ship and pipe suspension tower configuration. Larger lengths result in savings in coupling units and deployment time. The airlift system requires compressed air piping. Additional pieces of equipment for this system include pipe coupling units, deadweights for tensioning the pipestring, and pipeline fairing, if warranted, to reduce the dynamic effects on the pipestring.

Due to the endless number of possible collector unit designs, no one unit will be described. Instead, this scenario treats the collector unit as a single cost item.

The items included in the pumping system, the dredge pipeline system, and the collector unit itself have some back-up units stored on the miner. The weight capacity and storage space requirements for these items are taken into account when designing the mineship.

The ore-handling equipment requires equipment for interfacing the mineship and the pipestring; a separate unit for dewatering the nodules slurry when it reaches the surface; a slurry system or conveyors for moving the nodules to the stowage holds on the mineship; and a slurry self-unloading system for transferring the nodules from the mineship holds to the transport vessels.

The mineship is subsectored into the hull structure group, the hull engineering components, primary propulsion and the main power plant machinery, special navigation and dynamic positioning equipment, special hotel requirements, a helicopter platform, and possibly special towing equipment for towing the ore transport ship during the nodule transfer operation. The main power plant is a diesel electric plant which utilizes several diesel engines to drive generators. The generator output, in turn, can be switched to propel the mineship to the minesite, propel and position the mineship during the mining operation, handle the stringing and recovery of the pipestring,energize the pumps and ore transfer systems, and handle the large hotel loads.

A special navigation system must be developed to allow the miner to follow a predetermined mining path. This system includes electronic navigation equipment for position finding, bow and stern thrusters for position keeping, and an electro-mechanical automatic control system for interfacing the electronics and the propulsion and ship-control equipment.

The mineship schedule requires the vessel to be on station 300 days per year. The assumption is that the mineship is at the maintenance ship yard/base during the height of the Northeastern Pacific extratropical cyclonic storm season (15 August to 15 September) and departs for the minesite for its "year's work" on or about 16 September. The ship's crew (captain, deck and engineering officers, deck and engine crews, steward and steward's department) sail the ship to the minesite and place it over the previously positioned seabed transponder array. The mining technicians and crew then proceed to put the collector overboard, pass the hose or flexible bridge to the derrick by keel-hauling its upper terminus, and "string" pipe until the dredge head is landed. Control of the ship (except in navigational or weather emergencies) is then passed to the mining control center and nodule dredging commences according to the previously developed mining plan.

Except for the maintenance and repair (M&R) of the ship and mining equipment, mining proceeds around the clock for the balance of the year (weather permitting). One fulltime ship and mining crew board the shuttle ship about four days before "duty time," proceed to the minesite, transfer to the mining ship, work one month, reboard the shuttle ship, and return to the logistics base for R&R, resulting in five-and-one-half-months working at sea, one half-month working in port (during overhaul), one-plus month in transit, and five months R&R and vacation annually. This schedule (similar to oil platform overseas practice) would justify 12-hour-on, 12-hours-off work days and rewarding salaries as well as comfortable on-the-job working and recreational surroundings.

2. Cost Estimates

Two mining vessels are assumed in the present model, each of which operates independently of the other and is serviced by a separate fleet of transport vessels. The cost estimation, therefore, finds the cost of one mineship and then multiplies the overall cost by two.

Each mineship operates 300 days per year and mines half the overall nodule tonnage, i.e., 1,500,000 dry tons annually. The storage capacity of the mineship must be sufficient to accommodate the decanted nodule tonnage mined between two successive visits of an ore transport vessel, plus a margin. Given the large cost associated with the size of the mineship, the required capacity is determined by the number of transport ships and the distance between port and site (i.e. the mining sector follows the transportation sector).

As indicated earlier, the mining vessel is a modified ore carrier designed to accommodate the mining equipment and additional hotel space. Costing also follows closely data derived from oil drilling rig experience. Data for ore carriers are used to estimate the hull weight and outfit weight, while the dimensions are changed to accommodate the moonpool, derrick and associated equipment, the larger propulsion and power system required to propel the vessel and drive the pumps and positioning thrusters, and the larger crew and personnel spaces. An estimated 100 people will be required on board during operations.

For purposes of capital costs and operating costs estimation, the mining sector described above is broken down into six subsectors, each of which is further divided into subsubsectors. The subsectors are described below. More detailed descriptions of the subsubsectors appear in Appendix 2.

Capital cost estimates are derived in two ways, or some combination thereof. In many instances -- at the subsector or subsubsector level -- empirical data from industry sources have been used. In particular, data gathered for NOAA's Office of Ocean Minerals and Energy by Professor John Flipse have been relied on. (See Appendix 2.) In other areas, particularly where there has been only limited industry experience with the full scale technical components of a subsector (e.g., in the dredge pipeline, collector unit subsectors, and some subsubsectors of the mineship), sizing analyses were completed on component units, using parameter values stated in Appendix 2. In these cases, the weight of the equipment, its power requirements (if any), the capital costs, and the annual operating costs were calculated. The calculations are based on the sizing analyses, using the industry empirical data as a parallel check and frequently as inputs into the costing process.

A fluid (hydraulic lift) system is proposed to convey the nodules to the surface, by pumping a mixture of nodules and sea water through a vertical pipestring. The conventional slurry pump system uses submerged, multi-stage centrifugal pumps to lift the mixture to the surface.

In developing costs, the initial objective is to determine the necessary pumping power, which is directly related to the friction headloss in the pipestring and the sinking velocity of the nodules suspended in water. The total power required is composed of the frictional power lost on the walls of the pipe, the differential potential energy of the nodules, and the wake losses of the nodules in the water. Thus the main parameters are the flow rate of the nodules, the diameter of the pipestring, and the spatial concentration of the nodules in the slurry. The power cable is costed based on the total length required to service the pumps, distributed over three stages along the pipe length, and the collector. The auxiliary equipment in the pumping system consists of control equipment.

For cost summary, see Table II - 3.

TABLE II -3

CAPITAL COST SUMMARY

IN MILLIONS OF 1980 U. S. $ (PER MINESHIP)

8.1 Equipment and Supplies Handling	17.05
8.2 Nodule Pumping System	12.40
8.3 Dredge Pipe	19.60
8.4 Collector	3.50
8.5 Ore Handling	10.20
8.6 Mineship	90.37
TOTAL CAPITAL COST	$153.12

OPERATING COST SUMMARY

IN MILLIONS OF 1980 U. S. $

1. Maintenance and Repairs	15.37
2. Crew Salaries and Costs	9.94
3. Fuel Costs	4.68
4. Insurance and Lay - up	2.80
TOTAL OPERATING COST	$ 32.79

TOTAL CAPITAL COST FOR TWO MINESHIPS	$306.24 M
TOTAL OPERATING COST FOR TWO MINESHIPS	$ 65.58 M

E. Marine Transport (Sector 3)

1. Description of Assumed Events

The nodules will be carried from the mineship to the dedicated port facility by a fleet of equal sized bulk ore carriers. At least two of these transport ships are provided in the system to minimize vulnerability to total stoppage. Their size and number is governed by draft restrictions in the dedicated port (and any other ports of call), the distance from the minesite to that port, the nodule load to be serviced, and the delay time associated with transferring the nodules and maneuvering the vessel both at sea and in the port. Additionally, the number of mineships required is reflected in the size and number of ore carriers utilized, thus underlining the interdependence between mineship and transport sizing and design procedures.

The ore transport vessels are designed to carry a dewatered slurry of whole nodules. These vessels are fitted with a manifold and piping system for receiving the slurried nodules from the mineship and distributing it to the respective holds. The slurry holds in the ore carrier are hopper shaped, with smooth sides, to expedite cargo removal. Slurry water in the holds is decanted.

Fuel for the miner is stored in dedicated storage tanks, with provisions for pumping these supplies from the transport to the mineship through a flexible, floating umbilical, discussed previously in the mining section. Additionally, special equipment must be developed to allow the mineship and transport vessel to transfer nodules and fuels. This equipment might include dynamic positioning equipment for the ore transport, (Note: the mineship is assumed to be dynamically positioned also), some type of towing system where the mineship tows the transport during transfer operations, or possibly a combination of the two. The design of this interactive system is conducted during the R&D period.

When the ore transport vessel reaches the port facility, the nodules are removed from holds by portable, dockside slurry units. However, as an alternative to this baseline system, the ore carriers can be fitted with their own internal unloading system. Such a system is similar to that employed by the mineship. Water jets located in each hold of the vessel are directed into the stowed nodules, thus slurrying the ore which then flows into a collection sump under each hold. Slurry water is added to attain the proper mix for pumping the nodules to a shoreside holding pond.

If ocean dumping is selected as a viable means for the disposal of tailings from the process plant, slurry discharge ships could be used. This option results in the use of larger slurry transport ships in combination with disposal barges for handling the excess wastes. The larger transport size results from the extension of port time for these vessels to load outbound tailings for disposal. The waste slurry is pumped overboard by the ship's equipment while the ship is underway, at full speed, in deep water, and en route to the mining site. This alternative assumes that the discharge of wastes at sea will be permissible.

2. Cost Estimates

The costing of the ships that will carry the nodules from the mineship to the port is based on data from existing ore carriers as outlined in Appendix 3. The results were comparable to data collected by Mr. Ben Andrews, consultant to NOAA, Office of Ocean Minerals and Energy (See Appendix 3).

Since the number and size of ships has a significant influence on the transportation sector cost, the selection is made by a simple algorithm taking into account the distance from port to site, the annual nodule tonnage, and the port restriction. Other factors are the ship speed which may be required to change for fuel efficiency, the annual operating days, the transport efficiency, and the time to load and unload the nodules.

Additional equipment is required to handle the slurry on board, i.e., load and unload the slurry, dewater, and decant it. Also special equipment is needed for the at-sea transfer of nodules and the refueling of the miner.

A special shallow ship design may be used when required, to reduce the total number of ships. This shallow design allows a draft reduction up to 10% over a conventional design.

The total capital cost for the transport ships is based on direct cost estimations for U. S. construction. This includes

-- Labor Cost
-- Material Cost
-- Overhead Cost
-- Profit
-- Slurry System Cost

The parameters in the capital cost estimations are the cost per manhour, the price of steel, and the efficiency of the shipyard. A direct cost estimation has the advantage of evaluating directly the influence of parameter changes on the total capital cost. Sources of uncertainty are the variations between cost price and market price for the transport ships.

The annual operating cost has been divided in the following costs:

-- Crew Salaries
-- Maintenance Cost
-- Insurance Cost
-- Fuel Cost
-- Port Charges
-- Lay - up Charges

Empirical data obtained from the industry were used to estimate these costs. The salaries of the crew and the price of fuel are the most important parameters, which can change the operating cost significantly.

For the base case (a yearly production of 4,500,000 net short tons, a distance to site of 1,750 nautical miles and a draft restriction of 40 feet) four transport ships of 44,700 DWT are required. Characteristics are given in Table 1.

TABLE II - 4

PRINCIPAL CHARACTERISTICS TRANSPORT SHIP

L_{BP}	=	631 ft.	Δ	=	55,000 Tons
Beam	=	97 ft.	DWT	=	44,700 Tons
Depth	=	52 ft.	Light Ship	=	10,300 Tons
Draft	=	38.3 ft.	MCR	=	16,850 HP
C_b	=	0.82	V_s	=	15 knots

The total capital cost for four transport ships of 44,700 DWT is 200.88 M.

The annual operating cost for the base case with a 180 Centistroke Diesel fuel at a price of \$158 / tonne is \$ 22.08 M.

F. Ore Discharge Terminal (Sector 4)

1. Description of Assumed Events

An ore discharge terminal facility is developed in a deepwater port on the West Coast of the United States. This facility serves as the base for off - loading the ore from the transport vessels and preparing it for piping to the process plant. Additionally, at this facility the fuel and water supplies for the miner are loaded onto the ore carriers for the return trip.

This terminal will be located in a deepwater port having a minimum water depth of about 40 feet in salt water at low tide. This depth is the limiting factor in the ore carrier design. The distance between the port and the process plant should be as small as possible, with zero to 60 miles as the approximate suitable range. The closer the processing plant can be situated to the port facility without causing undue expense, the better. This distance is assumed to be about 25 miles (mid-range) as a central value.

The ore discharge terminal requires 15 acres of land (more if ocean dumping is used). The assumption is that this facility will be leased and thus all land preparation will be complete including provisions for utilities, sewerage, storm drainage, fencing, parking and other sites services. The building structures at the port are minimal and probably include a small office for administrative personnel, several light-duty maintenance buildings, and a pump house for the port - to - plant nodule slurry pipeline.

A pier and adjacent dolphins are provided for mooring the ore ships. Probably only one dock facility is necessary. However, if there is any significant overlap in port time for the various transport vessels due to the number of ore carriers and their respective schedules, an analysis must determine whether it is more practical, financially, to build a new dock facility or to slow down the trans - port vessels, resulting in some increase in size and/or number of required vessels. The pier must be strong enough to support several movable cranes mounted on a rail system. These cranes suspend the portable slurry discharge units to unload the ore transport vessels. The berth for these vessels has a water depth at least equal to the loaded draft of the vessels, by dredging if necessary. If an access channel to connect the berth with the main channel is required, more dredging must be undertaken.

The portable slurry units and their related piping are designed to unload the ore carriers in under 24 hours to facilitate quick turn - around of the ore carrier. The nodules are discharged into a nodule storage pond at the port facility. This pond is large enough to handle at least two shipsloads of nodules, and allow surge capacity if the port - to - plant pipeline should be out of service temporarily. The slurry discharge units utilize a closed loop water system which requires a contaminated salt water recycling tank of very large capacity. This tank should provide enough water for start-up, plus an hour's operation.

The terminal facility could have provisions for bunkering the ore transport vessel. The gear includes one or more pipelines from a remote source in the port on on - premise tankage. In both cases, however, additional piping and pumps are required to load the transport vessel. An alternate method of bunkering is a bunkering barge which ties up to the transport vessel and fuels it from there. For this analysis, the ore carriers, as well as the mineships, are powered by diesel engines; thus, both vessels require diesel fuel.

Power for the port facility is provided from the grids of local power companies. The major power consumption occurs when unloading the nodule carriers and pumping the nodule slurry from the terminal to the processing plant. (The nodule pipeline and its related equipment will be discussed in Section H.)

If ocean dumping of process wastes is chosen as a viable disposal technique, the terminal facility must be expanded to receive this waste and load it onto the disposal vessels. This operation requires the construction of tailings ponds capable of storing all the waste produced by the processing plant between the arrival of successive transport vessels, plus some surge capacity to allow flexibility in vessel schedules. In addition, more dock space may be required for loading the disposal barges used to handle the excess waste which cannot be handled by the ore transport ships.

To achieve rapid loading of tailings onto the transport ships and barges, a substantial pumping system is necessary. Several thousand kilowatts of electric power are needed. This power requirement could be several times larger than that for the smaller slurry pumping station pipeline, which would work around the clock rather than every few days. Such peak power requirements would result in the need for more transformers and possibly the use of diesel engines or gas turbines to produce power locally (at the terminal facility), if the power utility could not meet the increased demand.

2. Cost Estimates

The assumed ore discharge marine terminal is located on the West Coast of the United States. It must be able to accommodate the ore transport vessels of 45,000 DWT for the base case.

The costing work includes the expected capital costs of construction of the marine terminal, as well as the annual operating costs.

The marine terminal sector is grouped for capital costing in the following subsectors:

4.1 Terminal Land (in the base case is treated as leased land)
4.2 Terminal Site Development
4.3 Terminal Buildings
4.4 Pier and Pier Equipment
4.5 Dredging
4.6 Fuel Pipeline
4.7 Slurry Discharge Units and Related Piping
4.8 Nodule Storage Basin
4.9 Water Recycling Tankage and Return Water Piping

The capital costs for the marine terminal were based on data relevant to the San Diego Port area. Therefore, it was possible to make cost estimations on the subsector level depending on the size of the transport ships.

The operating costs were listed in seven different categories:

Maintenance and Repair
Labor
Utilities
Insurance
Taxes
Lease Fees
Miscellaneous

Labor cost and utilities were costed directly. The other operating costs were calculated as a percentage of the respective capital costs.

For cost summary, see Table II - 5.

TABLE II - 5

ORE DISCHARGE TERMINAL COST SUMMARY

(In Millions of U. S. $)

ITEM	CAPITAL COST
4.1 Land	0.87
4.2 Site Development	1.32
4.3 Buildings	10.96
4.4 Piers and Cranes	1.48
4.5 Dredging	0.11
4.6 Fuel Pipelines	5.73
4.7 Slurry Discharge and Piping	1.65
4.8 Nodule Storage Basins	0.75
4.9 Water Recycling Tankage	
	$22.87 M

ITEM	OPERATING COST
M&R	1.23
Labor	.95
Utilities	.25
Insurance	.23
Tax	.23
Leases	.30
	$ 3.19 M

G. Marine Support (Sector 8)

1. Description of Assumed Events

A fast ship is available (through purchase or charter) to transport crew and service personnel between the mineship(s) and a logistics base ashore. This vessel also handles mail, films, spare parts, food and supplies for the miner(s). The supply vessel has adequate hotel accommodations for crew replenishment. The number of crewmen handled per trip is a function of the frequency of calls the vessel makes at the mineship, the crew schedules, the number of mineships to be serviced and the distance between the mineship and the logistics base. This supply vessel is equipped with a small, medium-lift helicopter and associated helopad for emergency transfer of people and equipment to the miner. If the vessel size is adequate, it may also be equipped to handle a portable deep ocean recovery system designed to be used for locating and recovering lost collectors. This recovery system is stored at the logistics base when not in use.

The logistics base ashore can be at an existing port located as close to the minesite as possible (alternatives include Hawaii and San Diego). This support vessel terminal serves as the home base for the mineship supply vessel and possibly for the P&R research vessel and laboratories. The port which houses this terminal need not be a deepwater port as required for the ore ships, but should have enough channel depth to accommodate the research and supply vessels. A 20-25 foor depth would probably be adequate.

The land requirements for the logistics base are not excessive: enough acreage to support a P&E lab and storage facility, a parts warehouse and supplies logistic office for the mining operation, one or more piers for mooring the vessels, fuel pumps, and piping for bunkering and replenishing the vessels.

Financially, the most favorable arrangement is probably to lease the terminal facility, which then requires little or no site preparation and has all utilities already in place. The only major capital expenditures involve the construction or renovation of a pier with a movable crane for servicing the vessels and the construction of the required support buildings (labs and warehouses) as outlined above. Dredging to provide clearance at the vessel berths and for access to the main channel must also be considered.

2. Cost Estimates

The crew and supply vessel is a 170 ft. long vessel running at 20 knots, between a port facility assumed in Hawaii and the minesite. Twenty trips per year are assumed. The vessel is equipped with thrusters. Such supply vessels have not been constructed yet for long distances and require an extension of the state of the art. A 10% over the capital cost is allowed for new design fees. A research and survey vessel is also included, capable of staying at sea for long periods of time with roll stabilizers and positioning thrusters. The vessel is chartered on an annual basis.

The support vessel terminal is obtained through leasing agreements. The annual cost is estimated for two acres of port land including 10,000 sq. ft. of building space and 200 ft. of pier space. Mobile cranes will be provided.

For cost summary, see Table II-6.

H. On-Shore Transportation (Sector 5)

1. Port to Process Plant Slurry Pipeline

a) Description of Assumed Events

The manganese nodules are transported to the process plant by a slurry pipeline system, with slurry water recycled to the port facility. The system requires both slurry and decant piping, slurry and decant pumps, a slurry water storage tank(s), and right-of-way land for the pipelines. Enough slurry water storage is provided at the port facility for start-up procedures. The pipelines are buried only if required by local ordinances.

TABLE II - 6

COST SUMMARY (BASE CASE)

(In millions of 1980 U.S.$)

CAPITAL COST	
Research Vessel (Chartered)	--
Supply Vessel	1.80
Marine Terminal (Leased)	--
TOTAL	$ 1.80 M
OPERATING COST	
Research Vessel	3.50
Supply Vessel (including helicopter)	0.80
Marine Terminal	0.38
Crew Training	0.20
TOTAL	$ 4.88 M

b) Cost Estimates

A cost estimation is made for a slurry pipeline capable of transporting 4,500,000 wet nodules over a distance of 25 miles and a height difference of 1,200 feet. As explained in Appendix 4, part I, the design methodology for such a slurry pipeline is not well established and the power and cost calculations should be regarded as a first approximation.

The following subdivision is made:

Slurry Pipeline & Equipment

Transportation Required Land

The pipeline cost is derived from costs of existing pipelines. The slurry pipeline land cost is evaluated by summing the direct land cost and the surveying and preparation costs. A 50-foot right-of-way is assumed. The operating costs are divided into energy, labor and maintenance cost.

A summary of the capital and operating cost for the port to process plant slurry pipeline is given in Table II-7.

TABLE II - 7

SLURRY PIPELINE COST SUMMARY

(In millions of 1980 U.S. $)

Capital Cost	10.89
Operating Cost	3.20
Land Cost	0.40

2. Waste Slurry Pipeline

a) Description of Assumed Events

The disposal of process wastes by slurry disposal ponds requires the use of a waste slurry pipeline system. This pipeline, very similar to the nodules slurry pipeline, is a closed loop system with slurry water being recycled to the process plant for reuse. The system requires both slurry and decant piping, slurry and decant pumps, a slurry water storage tank(s), and right-of-way land and land preparation for the pipeline. The pipelines are steel units with pumping and recycle water storage facilities located at the process plant.

b) Cost Estimates

The waste slurry pipeline differs from the port to process plant pipeline because in this case the particle average size is 100 microns. The distance to the waste site is assumed to be 60 miles. A height difference of 1,900 ft. was taken into account.

The waste pipeline was also subdivided into two sub-subsectors:

Slurry Pipeline and Equipment

Transportation-Required Land

The cost methodology is similar to that of the port-to-process plant slurry pipeline.

A summary of the costs is given in Table II-8.

TABLE II-8

WASTE SLURRY PIPELINE COST SUMMARY

(In Millions of 1980 U.S. $)

	CAPITAL COST	OPERATING COST
Waste Pipeline	22.40	4.48
Land Cost	0.96	0.00
	23.36	4.48

3. Roads and Railways

a) Description of Assumed Events

The transportation of supplies, products and personnel to and from the process plant and waste disposal site necessitates construction of access roads and/or railways to these facilities. The port facilities are assumed to be sited in fully developed areas; therefore, no new, long access roadways are anticipated.

The process plant requires both rail and road services due to the large volume of supplies and products to be handled. The process plant is located within five to 10 miles of a major rail line; thus a rail spur of this length is required. In addition, substantial access roads connecting with a major thoroughfare and capable of handling frequent heavy trucking are required. The waste disposal facility also requires access roads capable of supporting heavy trucking.

Both the access roads and the rail spur line require the purchase of right-of-way land. The land must be surveyed and prepared before pavement or tracking can be installed.

b) Cost Estimates

The actual cost will depend significantly on the specific location chosen. For this purpose the following costs were chosen as tentative preliminary estimates assuming that no major road construction will be necessary.

The cost of roads, access roads, and right-of-way land = 2×10^6 U.S. $.

I. Processing (Sector 6)

1. Description of Assumed Events

Copper, nickel, and cobalt are recovered from the manganese nodules using a reduction/ammoniacal leaching technique. This hydrometallurgical processing is done in a plant designed to handle three million short tons of dry nodules per year. Reduction/ammoniacal leach processing has been chosen as an illustrative example and does not necessarily represent the exact system that any consortium might employ.

Equipment used in this process is grouped into functional units called subsectors to facilitate capital cost estimation. The Materials Storage, Handling, and Preparation subsector ensures that the bulk raw materials are delivered to the process stream in the appropriate form at the proper rate. Coal, lime, and limestone, which enter the plant by rail, are unloaded at a dumping station and then conveyed to their appropriate storage facilities. Nodules, which are pumped to the plant via slurry pipeline, are distributed into settling ponds for storage. When needed, these materials are reclaimed from their storage facilities, prepared for use, and conveyed to their destinations. For the nodules this preparation includes grinding in primary and secondary cage mills, combining with drying in fluid-bed dryers.

Entrained nodule fines are removed from dryer off-gases with cyclones and electrostatic precipitators and then returned to the process stream.

The Nodules Reduction and Metals Extraction subsector first prepares the nodules for release of the valuable metals (reduction) and then leaches out these metals with an ammonia liquor (extraction). The nodules are reduced in a fluid bed roaster and cooled in water sprays as preparation for extraction. Off-gases from these operations are treated in waste heat recovery boilers to remove the heat and in cyclones and electrostatic precipitators to remove dust. In the extraction steps, the nodules are quenched to tanks of recycled ammonia leach liquor, pumped in slurry form to agitated aeration cells, and then passed to a thickener circuit for separation. The covered thickeners separate the liquid (containing dissolved metal values) and the solids (tailings).

The Metals Separation subsector separates the valuable metals from each other by selectively extracting each dissolved metal out of an organic medium. A liquid ion exchange circuit with eleven stages of mixer-settler units and necessary tankage hardware is used to transfer the dissolved metals from the leach liquor to the organic, then to scrub the organic of its ammonia, and finally to strip the organic of each of its metals (nickel, copper, and cobalt) independently.

The Reagent Recovery and Purification subsector washes the valuable reagents and metals out of the by-products of various operations and prepares those reagents for recycling. The tailings slurry, produced in Nodules Reduction and Metal Extraction, is washed of its residual metals in a five stage counter=current decantation unit. Barren tailings from this washing are steam stripped of their ammonia reagents in a stripping tower and then prepared for disposal. Ammonia sulfate, produced in Metals Separation and elsewhere, is reacted with slake lime in a lime boil vessel to produce ammonia which is returned to the process stream. Vent gases are stripped of their ammonia in absorbers, condensers, and scrubbers. The ammonia is then used to rejuvenate the circulating leach liquor.

The Metals Recovery and Purification subsector produces marketable metals and materials from the products of the Metals Separation subsector. Most of the nickel is recovered using electrowinning techniques. The nickel electrowinning section includes stripper and commercial cells; facilities for starter sheet preparation, cathode bag handling, organic removal, cobalt removal; and the necessary electrical equipment such as rectifiers. Copper is also recovered using an electrowinning technique. The copper electrowinning section includes stripper and commercial cells, facilities for starter sheet preparation and nickel removal, and necessary electrical equipment. Cobalt is removed from the raffinate liquor by precipitation with hydrogen sulfide and is then recovered, along with nickel powder and copper/zinc sulfides, by selective leaching and hydrogen reduction. This section includes sintering and packaging machines along with numerous reactor and separation vessels and necessary tankage.

The Plant Services subsector provides many of the support operations needed to operate the process. Included in the subsector facilities for the storage of materials, supplies, and products; the production and distribution of steam; the generation of producer gas for nodule reduction and combustion gas for nodule drying; the production and distribution of part of the power required to run the plant; the cooling, treatment, and distribution of water for the various processes; and the treatment and release of off-gases.

The processing plant is assumed to be located in Southern California in an area which can supply all the necessary infrastructure for the facility. This infrastructure includes electric and water utilities; qualified manpower; accessible road, rail, and air transportation networks; police and fire protection; business services such as office supplies vendors as well as food and maintenance services; and housing, hospitals, and recreation facilities for employees.

The processing plant site requires about 500 acres of land. About 25 percent of this land is allocated to nodule storage and decant ponds; coal, lime, and limestone storage areas; and a plant run-off and emergency waste storage area. An additional 75 acres are occupied by the major processing equipment, including the thickeners, and the remaining acreage is used as plant boundaries and as yard spaces for facilities such as the rail system.

2. Cost Estimates

a) Capital Costs

Capital cost estimates for the processing plant are based on the description of the reduction/ammoniacal leach process in Dames and Moore (1977). Table II-9 shows the fixed capital investment estimates for each of the six subsectors and the land.[3]

A more detailed cost breakdown appears in Appendix 5.[1] The total fixed capital investment for the processing plant is $449.1 million.

TABLE II-9

CAPITAL COST SUMMARY FOR PROCESSING SECTOR*

(In Millions of 1980 U.S. $)

	Fixed Capital Investment
Material Storage, Handling and Preparation	76.8
Nodules Reduction and Metal Extraction	51.5
Metals Separation	45.0
Reagent Recovery and Purification	45.5
Metals Recovery and Purification	95.1
Plant Services	134.3
Land	1.0
TOTAL	449.1

*For a plant processing 3 million short tons of dry nodules per year using a reduction/ammoniacal leach technique.

b) Annual Operating Costs

In addition to capital costs, the processing plant also incurs annual costs. These annual operating costs are based on a three-shift, 24-hour-day, 365-day-year operation. Down times for maintenance and repairs will result in a full production schedule equivalent to 330 days per year.

Table II-10 summarized the annual operating costs. The Materials and Supplies and Utilities and Fuel costs are estimated on the basis of energy and materials balances developed in Dames and Moore (1977). The Labor cost is based on the assumption that the plant will employ 500 people including operating, maintenance, supervision, general plant, and administrative personnel. Capital Related charges which include machinery replacement costs, janitorial and office supply costs, state and local tax liabilities, and insurance premiums are estimated as a percentage of the total fixed capital investment. The total annual operating cost is about $99.6 million.

TABLE II-10
ANNUAL OPERATING COST SUMMARY
(In Thousands of 1980 U.S. $)

Materials and Supplies Costs	3,990
Utilities and Fuel Costs	47,520
Labor Costs	16,680
Capital Related Charges	31,430
TOTAL	99,620

c) Summary and a Caveat

The fixed capital investment required for a plant that processes nodules with reduction/ammoniacal leach technique is $449.1 million (1980). The uncertainty of this estimate is plus or minus 25 percent. The total annual operating cost is about $99.6 million (1980).

The processing plant is an extremely complex unit. All of its functional parts are very independent. As a consequence, the costs presented for this sector cannot be easily manipulated to derive the cost of a plant that is significantly different than the one described above. The costs presented here are valid only for a plant that processes 3 million short tons of dry nodules per year by the reduction/ammoniacal leach method.

J. Waste Disposal (Sector 7)

1. Description of Assumed Events (See also H. On Shore Transportation)

The slurried tailings are contained in impermeable slurry tailings ponds. These tailings ponds are constructed at a waste site located as close to the processing plant as economically and environmentally possible. The distance from the plant to the waste site is probably less than 100 miles.

Essentially, this tailings disposal method consists of constructing earth embankments, behind which waste materials are deposited in slurry form. The embankments can be either a total enclosure, or a cross valley or side hill type: for this analysis the total enclosure technique is assumed to be employed. The tailings are transported to the disposal area in a slurry pipeline and deposited into the empoundment through a series of distribution pipes and spigots. The waste slurry settles in the ponds to higher solids contents, and excess transport water in decanted off and recycled to the plant for reuse. The design of the tailings embankment will be such that it is stable under both static and dynamic loading conditions and capable of handling floods. It will also be designed so that seepage through the pond bottom and embankments is controlled by using impermeable synthetic liners and/or compacted impermeable clay liners if this type of material is chosen.

For one-year's production of wastes from a three-metal plant, a tailings pond of about 65 acres is required for tailings which accumulate to a depth of about 40 feet. However, this size can vary depending on the local evaporation rate at the waste site and the density to which the slurry settles.

Based on the above figures, the total waste disposal land usage for a 25-year project is about 1,700 acres.

To reduce initial capital expenditures, construction of all the tailings ponds required to handle wastes will not be undertaken at one time. Initially, ponds capable of handling the first three years of operations are prepared. In the third and subsequent years, additional ponds are added on an annual basis, so that a two-year capacity is at all times available. A decant pond to handle evaporation of excess water would be constructed initially if required.

The first step in the construction of these ponds is the stripping and stocking of topsoil for later use in revegetation. The tailings embankments are constructed in stages, with materials borrowed from inside and disposal area, if possible. Following the embankment construction an impermeable bed is developed using a synthetic liner on compacted clays. If the underlying soil or rock of the waste site is relatively impermeable, this step may not be required. Monitor wells must be constructed around the perimeter of the embankment to check for seepage. If appreciable amounts of seepage are detected, specially constructed wells or ditches around the perimeter of the embankments must be utilized to collect this seepage and pump it back into the tailings ponds. However, this is unlikely if the initial pond design and construction are adequate and proper operating and maintenance procedures used in its disposal area.

2. Cost Estimates

For the base case, the results are summarized in Table II-11, see Appendix 6 for further detail.

K. General and Administrative Costs (Sector 9)

The general and administrative (G&A) costs sector contains expenditures for leasing the consortium's headquarters, regulating compliance costs, and testing for the plant, mineship, and transport system.

Sectoring structure for G&A is as follows:

TABLE II-11

WASTE DISPOSAL COSTS BASE CASE

(In millions of 1980 US $)

CAPITAL AND LAND COSTS	
Land Cost (25 years)	3.25
Landfill and decant pond	1.50
Equipment and auxiliary	0.50
Surveying	0.13
Three Initial Ponds	9.90
TOTAL CAPITAL AND LAND COST	15.28
OPERTING COSTS	
FIRST AND SECOND YEAR	
0 ponds	0.00
Power, materials and supplies	0.30
Labor	0.30
TOTAL	0.60
THIRD AND SUBSEQUENT YEARS	
1 pond	3.30
Power, materials and supplies	0.30
Labor	0.30
TOTAL	3.90

Capital Expenditures (CAPCST)

Headquarters
Regulatory Compliance
Testing Costs

Operating Expenditures (OPCST)

Headquarters
Regulatory Compliance

Leasing costs for the consortium headquarters are assumed to total $22M during the investment period and $4M per year during production. Investment period expenditures are capitalized wherever operating costs are expensed. Regulatory compliance expenditures are presently assumed to be zero, although flexibility is provided to substitute a positive amount. All testing costs are one-time costs incurred in the last year of the investment period. These costs are thus capitalized and included in the CAPCST array for the G&A sector. There are no related operating costs. Total expenditures for testing the plant, mineship, and transport system are assumed to be $66.2M.

Working capital is specified in the model as a set percentage of full production operating costs. At present this factor is equal to 3.5% or approximately $75M.

III. FINANCIAL ANALYSIS

The financial analysis part of the model integrates cost information developed in the preceding sectors with the revenues expected over the anticipated life of the ocean mining operation. Assumptions about project timing, investment scheduling,debt financing, and annual tax liability are incorporated in this part of the program. These assumptions permit the model to project annual net cash flows. Subsection E describes the net cash flow estimation procedure. Using the projected annual net cash flows over the project's life, the model estimates the economic return of the ocean mining operation using various standard financial measures. For this study, three measures of profitability are calculated: net present value using adjusted present value methods, internal rate of return, and simple payback. The calculation and use of these measures are discussed in Chapter IV.

Assumptions as to inflation, escalation, debt and equity financing, metals prices, and project delays are reviewed in sections A through D.

A. Assumptions Concerning Inflation and Escalation

One basic assumption in the modeling of a project which is subject to dynamic conditions over time is the issue of inflationary versus real growth. Two treatments of this problem are usually encountered. The modeler either may account for inflation by building an inflation factor into the model over time or may express all costs and revenues in real (or constant) dollars as of a certain date and adjust these figures for real growth only. (Real growth, as opposed to inflationary growth, is that change in price/cost which is due to the unique characteristic of a product or input.)

We have elected not to reflect inflation in the model but to keep the costs and revenues in real terms. To do this, 1980 has been used as a price base. Cost estimates based on earlier real dollar costs have been adjusted using price indices to reflect 1980 dollars before they become inputs into the cost estimating process. Henceforth, throughout the program, constant 1980 dollars are used. The MIT model does, however, have the capability to add in an inflation factor, either across the board or in several different areas so as to permit varied inflation factors. It can also incorporate periodic changes in real growth.

In order to be consistent with the constant dollar concept, the inflation component of interest is not included in the development of the interest rate (see next subsection). Where any discount rate is referred to in this text, the intent is to signify the non-inflated, or "real" discount rate. It should be noted that in many concepts of discount rate used by analysts, inflation is built in, although this is not clear in all instances. An incongruity in this model lies in the fact that some tax benefits, such as carry-forwards or depreciation schedules, are received in future years and are thus expressed in nominal (not real) dollars. These benefits should thus be discounted at a nominal discount rate which would contain an inflation component. However, the existing model discounts all cash flows at a real rate of interest.

The real growth of costs and revenue can be factored into the model at the user's direction. Average annual real growth rates can be selected for capital equipment, commodity (metals) values, and operating expenditures. Current real growth of all three factors is presently assumed in the model to be zero.

B. Assumptions Concerning Debt and Equity Financing

Financing of the project can be by way of equity, i.e., the at-risk funds of the owners; by way of retained earnings; by way of debt of a variety of forms; by way of long-term leasing; or, by some combination of the above. Most frequently, owners will seek to borrow a substantial amount of the required funding, thereby gaining leverage on the use of their own funds. Under certain circumstances, some owners in comparable large volume projects have in recent years self-financed, i.e., provided the total funding themselves. The main example here is oil company fundings of production platforms. The actual form of funding may depend upon both who the parent is and the prospective cash flow of the project.

Whatever the choice, the amount of debt funding is additionally limited by the capacity of the cash flow to service the debt, i.e., to pay for the interest and repayment according to the terms of the loan. In the model, it is assumed initially that the owners will seek to use debt financing up to the limit identified above, i.e. when it is permitted by the cash flow. Normally, the maximum debt allowed is that which can be serviced using two-thirds of the debt-free cash flow. This is equivalent to the requirement 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 which in this study is set at 33 percent. At the user's discretion no debt (i.e., all equity) or any portion of debt up to that set by the limit identified above may be assumed. The form of debt financing assumed in the base case is a term loan of ten years.

The interest rate of the loan (the cost of debt) is in theory composed of three components: the real cost of capital, the risk premium, and the inflation rate. The real cost of capital in industrialized countries historically has been much lower than nominal interest rates, i.e, around three to four percent. The risk premium, recognizing the lender's evaluation of the risk attached to the project, may vary according to the nature of the project, whether the project is standing on its own or is guaranteed by the parent corporations and similar factors. A risk premium of from 2 to 4 percent is not uncommon. A third component, the inflation factors, is intended to reflect the lender's perception of what the inflation rate over the period of the loan is likely to be. In order to avoid becoming fixed in predicting the inflation component during a period of changing inflation rates, some financial sources now make medium term loans available with the interest rate pegged to go up and down in relation to the prime rates which is in turn related to the average rate of interest at which the lending banks may borrow funds from the Federal Reserve banking system.

The model has been set to use constant dollar costs rather than current dollar costs, and this principle has been extended to the interest. Therefore, the interest rate used in the model on the debt when it is present, comprises the first two elements, i.e., the real cost or capital and the risk element. The inflation component is not reflected in the interest rate charged.

One way of determining this is to take current interest rates and subtract from them the current rate of inflation. Another approximation reflects the practice of the federal government which frequently charges an overall, so-called social cost of capital that, similarly, is intended to exclude the inflation rate. In 1980, different agencies of the government used the figure of 10% for this calculation. In the initial set of assumptions in the model, the debt bears an interest rate of 5% comprising a working cost capital estimated at 3% and a risk assumption of 2%.

Analysts regarding a project frequently wish to be able to evaluate the project both with and without the advantages provided by the leveraging of the debt. (Similarly, they may wish to evaluate the project with and without taking into consideration advantages or cost arising from taxation). As explained below, the model provides analyses based on its ability to calculate internal rate of return with and without debt and with and without taxes. (See Chapter IV, section A.)

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. (This type of repayment plan is characteristic of bank mortgages to individuals for purchase of real estate). Alternately, term loans can be repaid in level principal payments. This, of course, results in higher interest payments in the early years of loan retirement.

C. Assumptions Concerning Metal Prices and Gross Revenues

Gross revenues are defined as total cash receipts from operations. In this study, the average annual gross revenue for each of the three metals is calculated as the average annual production yield multipled by the average annual price for the mineral. Thus, the total annual gross revenues for the project are equal to the sum of the gross revenues for each of the three metals recovered during processing.

1. Estimation of Metals Prices

Price projections for the components of the ores play a crucial role in determination of gross revenues (and therefore in the subsequent calculation of economic return). Economists typically estimate future price series based upon historical trends through the use of regression techniques. These estimates are adjusted to account for any possible market supply effects of particular ventures.

In many instances, highly uncertain economic conditions require a degree of healthy skepticism toward price projections. In a draft analysis of metals prices (November 25, 1980), Dr. Larry Rogers of NOAA's Marine Minerals Division notes that:

> For many commodities, price forecasting is fraught with difficulties. Under the rapidly changing conditions which characterize today's international economic environment, the task of price predictions becomes even more difficult. Because the future is uncertain, as well as for other reasons related to prediction models, price forecasts for the value metals in manganese nodules may not be expected to exhibit a high degree of accuracy.

However, for use in this study, price projections for copper, cobalt, and nickel must be developed for approximately the next forty years. A review of recent studies reveals estimates ranging from -2.1% real price growth for cobalt (Wright, 1976) to approximately +2.2% real growth for all metals (Pittman, 1980). Simple linear regression of historical data for the past nineteen years yields similar results.

Therefore, for the purposes of this study, we have assumed the following prices as "central values".

Metal	1980 Price (1979 Dollars)	Real Price Growth
Cobalt	5.63	0.0%
Copper	1.25	0.0%
Nickel	3.75	0.0%

2. Production Yield

As previously noted, average annual gross revenue is determined by the annual production yield and the average annual metals prices. The base case full-scale production yield is determined as follows:

Metal	Yield (million lbs.) = Level of Production x Metal Content x Recovery Efficiency
Cobalt	8.64 = 3MDST x 2,000 lbs./DST x 0.24% x 60%
Copper	74.10 = 3MDST x 2,000 lbs./DST x 1.30% x 95%
Nickel	85.50 = 3MDST x 2,000 lbs./DST x 1.50% x 95%

Production is assumed to be zero until start-up of commercial operations in year 22 when production scale is 50% for one half year. Beginning in year 23, production is full scale (100%).

D. Delays in Expenditures, Investments and Operations

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 as part of the project's scheduled life span, a period of which represents the sum of all anticipated project delays.

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.

These same economic influences and/or those resulting, for example, from prolonged labor contract disputes, can create a delay during the investment period. 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. Singularly or collectively, these delays may be among the costliest aspects of the preproduction and contract and construction phases.

Other possible delays may result from interruption of on-going operations. Whether because of union contract disputes, environmental protagonists' confrontations, litigation, or other sources, such delays may have serious impacts upon planned ocean mining operations. Concerns over minesite harrassment, operational constraints imposed by potential future regulatory regimes, and analogous matters associated with current Law of the Sea negotiations could all eventually materialize as operational delays during the first decade of at-sea operations.

Whatever the cause of the delays, one thing is certain: the impact of delay is costly. The model has the capability to measure the impact of five arbitrarily selected delay periods:

--Preresearch and Development Delay;

--Precontract and Construction Delay;

--Contract and Construction Delay;

--Precommercial Production Delay; and

--Commercial Production Operations 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 first potential delay period, denoted as the pre-R&D delay. The preinvestment delay period (which follows the premining R&D period) ends when investment begins. During the contract and construction (investment) phase, there is provision for a delay period of arbitrary length. Following the investment period, there is a pre-commercial production delay period which ends when production commences. The final delay period built into the model is one which can occur during commercial production.

E. 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 expenditures. In the model, the cash components are the annual gross revenues, the annual capital investment, total annual costs, and the annual tax payments. These components are discussed below.

1. 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. In the commercial production period, the central value level of annual processed nodule production is 3 million dry short tons, or 4 million tons of wet nodules taken from the ocean floor. (This value may be changed by the operator, within limits, as might be the case if the processing sector were to be changed to assume processing of manganese in addition to nickel, copper, and cobalt.)

Using average nodule composition and plant recovery efficiencies as specified by the model operator, the model calculates the annual production yields for nickel, copper, cobalt, and other minerals. It is assumed that the annual yield of each metal is sold through long-term contracts.

Using the long-run market price projections discussed in Chapter III. C, 1 and the estimated production yields, the annual revenues for each metal are calculated and then summed up to give total annual gross revenues from primary metals (nickel, copper, cobalt).

2. "Up Front" Costs

Two main kinds of costs begin as the preproduction phase of the project begins and continue in some form into the commercial production phase. They are the expenditures for Research and Development (R&D) and Prospecting and Exploration (P&E) activities described in Chapter II. A and C. As indicated there, these costs along with any feasibility or permitting costs are aggregated into either the capitalized or expensed preparatory costs accounts and thence to the Capital (CAPCST) and Operating Cost (OPCST) arrays.

As discussed in section III. 6, the financial analysis employed in the model provides that P&E and R&D costs expended up to the time of the economic analysis are sunk, i.e., omitted from the cash flows serving as the basis for the financial analysis.

3. Continuing P&E and R&D

As indicated in section III. D, costs are incurred during commercial recovery as a part of ongoing preparations. These costs may be either capitalized or expensed, depending on the timing of the costs and predelictions of the user. These expenditures are then brought into the capital and operating cost arrays discussed below, in a manner similar to the preproduction costs.

4. Annual Capital Investment

The annual capital investment is that portion of the total required project capital investment which is expended during any given year. In addition to those capitalized up-front and and continuing preparation costs identified above, the capital cost arrays for the different sectors (see sections II.C-K) are summed and allocated according to the capital requirements build-up schedule found in Table II-2. The portion of these requirements represented by equity capital plus any debt principal repayment during the amortization period comprises the annual capital investment for any year. See Appendix 8 for these sums an initial set of assumptions.

5. Annual Operating Costs

Annual operating costs include each year's operating costs aggregated on the different sectors described in Chapter II.B-K, plus marketing and general expenses not so aggregated, such as G&A expenses during the pre-production and contracting and construction phases which are taken into the working capital account. Marketing and general expenses are assumed to be of annual gross revenues.

Operating expenses are aggregated under the OPCST arrays and are given in annual units. Their sums, for an initial set of assumptions, are found in the printout in Appendix 8.

To provide working capital for operations, the annual operating expenses are increased in the first year of production by an operator-defined percentage. In the initial set of assumptions, it is assumed that working capital of approximately $75,000,000 is required. 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.

As noted above, total costs may be specified either in constant or current dollars. In all of our analyses contained herein, they are set in constant dollars.

6. Calculation of Annual U.S. Tax Payments

The typical corporation will use any flexibility provided in the IRS Code to maximize the present worth of the corporation. Flexibility results from various means of expensing capital investment expenditures, from investment tax credits, and from the use of various income deductions such as interest payment deductions, tax loss carry back/carry forward, and depletion allowance. The Tax Code as of 1980 is used as the basis.

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 operating costs. From this sum, various deductions are subtracted to yield taxable income.

a) Adjustments to Gross Income

i) Depreciation. Depreciation is defined as the accounting procedure used to distribute the cost of a tangible capital asset, less salvage value (if any), over the estimated useful life of that asset in a systematic and rational manner. The Internal Revenue Service requires that in order to depreciate an asset, it must have a useful life of more than one year. The IRS also suggests use of one of three generally accepted methods:

-- Straight line;
-- Declining balance; or,
-- Sum-of-the-years' digits.

-- Straight-line Depreciation. The straight-line method is simplest for computing depreciation. Under this method, the number of years of "estimated useful life" of the asset is divided into 1 (one) to obtain the depreciation rate. This rate (expressed as a percentage) is then multiplied by the cost of the asset less its estimated salvage value to obtain the annual amount of depreciation. This annual amount of depreciation is applied against income during each year of the asset's useful life.

-- 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 deduction and lower taxable income 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 to determine the year's depreciation deduction. However, the asset may not be depreciated below its reasonable salvage value. 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 straightline 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. 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.

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 recover fully 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.

-- Sum of the 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.

In accordance with the remaining life version of the sum-of-the years' digits method, a different fraction is applied to the remaining unamortized (or adjusted) cost each year to compute annual depreciation. The denominator of the fraction changes each year to equal the sum of the remaining years' digits. The numerator of the fraction also changes each year to equal the number of remaining years of useful life of the asset (inclusive of the present year). This method may only be used for assets which qualify for the declining balance method at twice the straight-line rate. To change from this method to any other requires prior written consent of the IRS.

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.

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.

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 credits and deductions.

iii) Depletion. Depletion to a miner is the reduction of value of the mineral-in-place resulting from the 'mining out' of an ore body. The U.S. Tax Code permits mineral producers to write off this reduction in value of the mineral resource via the depletion allowance. Thus, depletion is to the owner of a mineral deposit what depreciation is to the owner of a capital asset. Guidelines for the utilization of the allowance are published and updated annually in the Internal Revenue Service Regulations.

The availability of the depletion allowance for deep ocean mining is likely, but yet uncertain.

-- Economic Interest. The 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."

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 the miner will have a qualifying "economic interest" in the mineral in-place. In the baseline model, it is assumed that appropriate legislation assures the domestic ocean miner of an allowance for depletion of the minesite. In this baseline study, a 14% 'metal mines' allowance was included. The value of the transportation sector has not been included in the allowance base on the grounds that current law would require a specific request for its inclusion.

-- Allowance Determination. There are two methods for determining the depletion allowance: cost and percentage. As specified by IRS Regulation 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. 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 Regulation 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 which is 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 mining costs divided by total costs up to the point of sale. This determination is made by the following equation:

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

-- <u>Multi-Mineral Ore</u>. If the ore contains two or more minerals subject to differing rates of depletion, the total depletion deduction can be computed by using the 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.

iv) <u>Tax Loss Deduction</u>. If the ocean mining project sustains a net operating loss during the tax year, that loss may be applied as a deduction to previous and/or future years' earnings under the loss carry back and carry forward provision. If the loss for any tax year is incurred after 1975, the ocean miner may elect to forego the carry back period. In the model, provision is made to carry any year's operating loss forward as a deduction in the seven succeeding years and the carry back option is foregone.

v) Other Tax Deductions. Other deductions 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. Those having the most relevance to this study are:

-- deductions for state and local income tax and real
-- property tax payments;
-- deductions for annual business insurance premiums;
-- deductions for repairs, replacements and improvements; and,
-- deductions for the revenue sharing trust fund tax.

-- State and local taxes are applicable to those parts of an ocean mining operation located on shore and may try to tax the at-sea operation. For the current generation of mining activity, this would be the metallurgical processing plant, described earlier. 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 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.

Expenditures for machinery parts to maintain the machinery in an efficient operating condition are deductible business expenses. In the 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 result from extensive overhaul or replacement and have the effect of increasing the property value, prolonging its life, or making it adaptable to a different use. These expenditures are considered as capital investment and must therefore be capitalized and recovered through annual depreciation. In the model, it is assumed that the actual productive lives of the various components and facilities 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 than the asset depreciation range defined by the IRS, this working assumption is acceptable for project analysis.

-- Deep Seabed Revenue Sharing Trust Fund. Under the Deep Seabed Hard Mineral Resources Act of 1980, payments to the revenue sharing trust fund are presently set at 3.75% of the "imputed value" of the resource. Imputed value is defined as being 20% of the fair market value of the commercially recoverable metals and minerals contained in the resource. The fair market value of the resource is determined as of the date of removal of the resource and is based upon the most basic form of mineral or metal for which there is a readily ascertainable market price. The tax is levied upon use or sale of the resource, but not before 12 months after its removal.

The Act also specifies that tax provisions contained within the international Law of the Sea Treaty, if and when ratified, will take precedence over the above mentioned taxation structure. As the fate of the treaty is uncertain as of this writing, we have assumed the taxation structure as in the 1980 Act.

The U.S. Treasury Department treats this tax as deductible and not creditable. Thus, the revenue sharing tax is treated analogously to a royalty or "ordinary cost of doing business."

Subtraction of the deductions listed in the above sections from income before tax, credits, and deductions yields the project's income before tax and credits (taxable income).

b) U.S. Tax (before investment and foreign tax credits)

In order to calculate the U.S. corporate income tax, the marginal tax rate is applied to the income before tax and credits. Surtax exemptions allowed under the Tax Revenue Act of 1978 are included in the calculation of tax liability. For post 1979 tax years, the old corporate system of normal tax, surtax, and surtax exemption have been replaced by a graduated tax rate structure that provides for rate reductions to stimulate the economy.

The new rates are graduated over the first four $25,000 amounts of taxable income as follows:

Taxable Income	Tax on Column 1	$ on Excess
0	0	17
25,000	4,250	20
50,000	9,250	30
75,000	16,750	40
100,000	25,750	46

A total reduction of $7,750 in corporate taxes for the first $100,000 of corporate taxable income occurs in comparison to 1978 taxes. The 2% reduction for taxable income exceeding $100,000 is not included in the model. A flat tax rate is first applied to each bracket of taxable income, and a specified percentage of the excess income in each bracket is also taxed.

After the federal corporate income tax is calculated, this amount is adjusted through the use of tax credits to yield actual income.

c) Investment Tax Credit

Under the applicable Tax Code, a credit against annual tax liability is provided for qualified investment expenditures made during the tax year. Investment expenditures qualify 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. However, with used property, no more than $100,000 of the cost may be considered in determining the 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. The investment tax credit is now set at 10% as allowed by current U.S. tax law.

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. However, expenditures for wharves, docks, land and other property related to the production site are not considered qualified. Property in the nature of machinery is the principal type for which these credits apply.

The model considers 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.

d) Net Income

Net income is the remainder of profits after the tax liability is subtracted from the income before tax. This sum represents the major source of cash inflow from the ocean mining operation. The total net cash flow is equal to net income plus non-cash expenses. The calculation of net cash flow is summarized in Table III-1, following.

TABLE III - 1

NET CASH FLOW ESTIMATION SUMMARY

Annual Gross Revenues
- Annual Operation Expenses

Operating Profit (Gross Margin)
- Depreciation Expense

Earnings Before Interest and Taxes
- Interest

Earnings Before Tax, Credits, and Deductions
- Depletion, Tax Loss Carry Forward, and Revenue Sharing Tax

Earnings Before Tax and Credits (Taxable Income)
- Corporate Income Taxes

Earnings After Tax Before Investment Tax Credit
+ Investment Tax Credit and Foreign Tax Credit

Net Income
+ Non-cash expenses (depreciation, depletion, tax loss carry forward)

Net Cash Flow

IV. ECONOMIC RETURN ANALYSIS

This chapter examines the economics of a hypothetical deep ocean mining project as described in Chapter II. The economic return of a project in the future is obviously dependent upon many factors. This chapter identifies some to which the return is believed particularly sensitive.

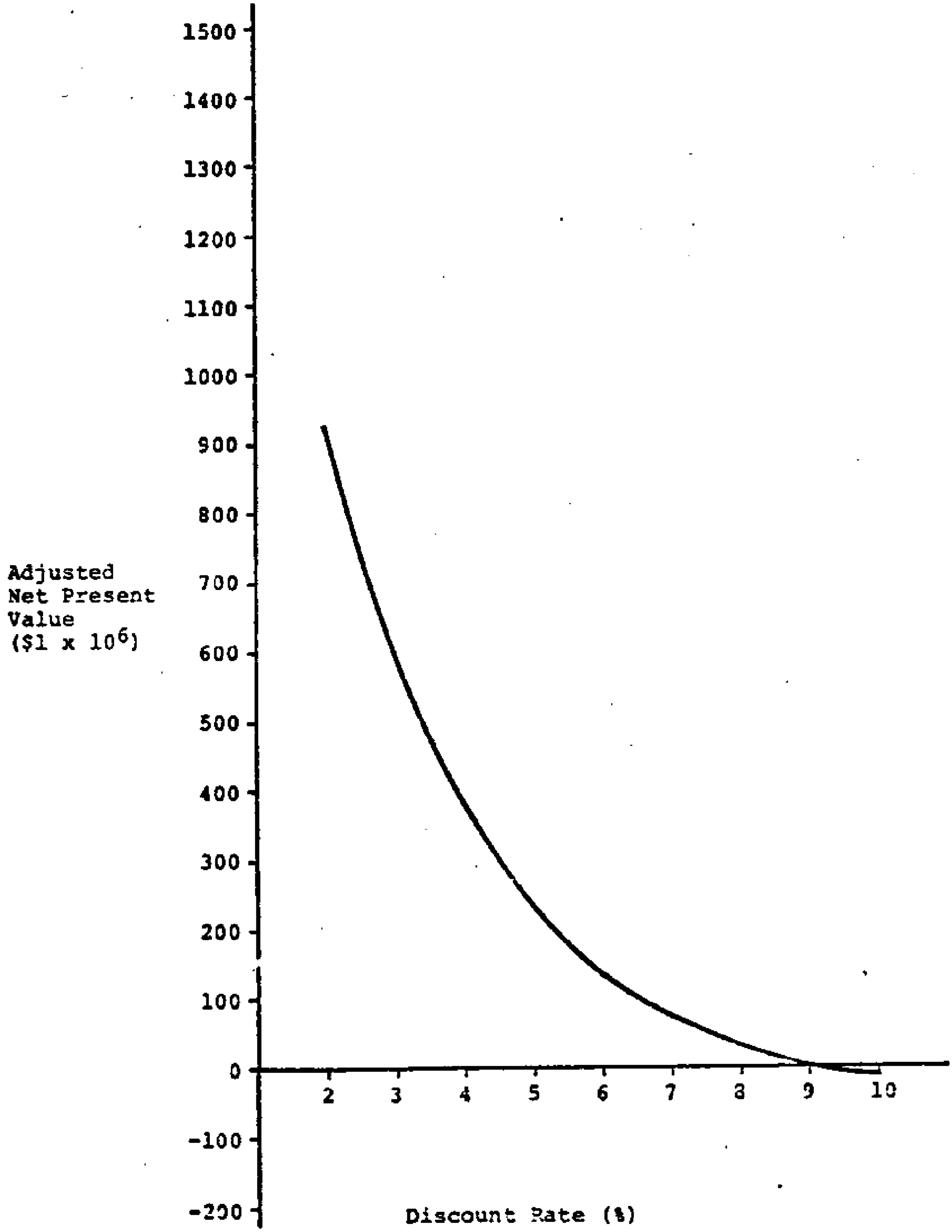
A. Financial Measures Used in This Analysis

Three measures of economic return are used in this chapter: adjusted present value(APV), internal rate of return (IRR), and simple payback period. These measures of return are computed using the project cash flows as described in Chapter III.

The APV is calculated using a preselected discount rate that is considered appropriate to the specific risk inherent in the project.[1] In a pioneer venture that is highly influenced by uncertain international law and variable economic circumstances, this "risk-adjusted" discount rate is especially difficult to estimate accurately. To allow for varying estimates of uncertainty, a range of asset discount rates around a "central value" of 6% (real) was selected. The APV of the project was calculated at each of these discount rates and is presented below in both tabular and graphical form. A complete table with all APV values is presented in Appendix 8. Throughout the analysis, a 50% debt:equity structure is assumed. In addition, the standard U.S.graduated corporate income tax scheme, as of Spring 1981, is used to calculate tax payments and debt-derived tax shields.

The IRR is defined as the discount rate at which the APV of the project is equal to zero. A useful means of presenting the return of a project is through the APV-discount rate graph.[2] These graphs portray the change in present value of a project as it is evaluated at varying discount rates, including that rate at which the APV is equal to

FIGURE IV-1: APV-DISCOUNT RATE GRAPH FOR A BASE SET OF ASSUMPTIONS



zero (see figure IV-1), i.e., the project's internal rate of return. At discount rates greater than the IRR an investor would normally regard the project as not economically profitable. Thus, a commonly accepted decision rule is reached -- accept projects for which the expected discount rate is less than the project's expected IRR. For comparison, all figures in this analysis include the project's graph for a base set of assumptions as a frame of reference.

The third measure of project return which has been provided is simple payback. The payback period provides an indication of the length of time necessary for the project to earn an amount equal to its investment. Industry frequently views payback as an important measure when undertaking projects during a period of capital constraint. Although the APV method of project evaluation is generally accepted as being more theoretically consistent than either IRR or simple payback, there are difficulties in its use, primarily in the selection of an appropriate discount rate. Because IRR does not rely upon a project-specific discount rate, and because the APV-discount rate graphs provide greater information regarding the project's return, these methods of presentation are used more heavily throughout this analysis. The project's payback period is presented because of its widespread use in practice.

B. Economic Analysis of a Base, an Upside and a Downside Set of Assumptions

1. Summary of a Base Set of Assumptions

Chapter II presented central value cost estimates for a deep ocean mining operation. These estimates, as used in the economic analysis, are summarized in table IV-1.[3]

TABLE IV-1

CENTRAL VALUE COST ESTIMATES
FOR DEEP OCEAN MINING

Sector	Costs ($M) Capital	Operating
1. Preparatory costs	30.00	142.00
2. Mining	322.62	64.88
3. Transportation	199.39	22.05
4. Marine Terminal	29.91	3.23
5. Onshore Transportation	24.43	11.66
6. Processing	458.20	100.10
7. Waste Disposal	16.87	5.47
8. Marine Support	1.32	5.61
9. General & Administrative	88.20	4.00
10. Continuing Preparations	0.00	6.00
TOTALS	1,140.94	223.00

As indicated in Chapter III, the legislation which the model considers includes a revenue sharing tax as set by the 1979 Deep Seabed Hard Minerals Removal Tax Act. The payment of this tax is not creditable; rather it must be considered a deduction against gross income. The standard U.S. graduated corporate tax structure is used to determine corporate income tax. It is assumed that the consortium will have an "economic interest" in the minesite. Thus, percentage depletion is allowed. However, the minesite is considered a foreign deposit. Therefore, the depletion allowance is 14% for all three metals recovered from the nodules.

Other variables in the base set of assumptions may be summarized as in table IV-2.

TABLE IV-2

SUMMARY OF ADDITIONAL VARIABLES FOR BASE SET OF ASSUMPTIONS

Schedule:[4]	
Initial delay	0 years
Pre-production period	.16 years
Pre-investment delay	0 years
Investment period	6 years
Pre-production delay	25.6 years
Costs:	
Capital	$1,140.94 MM
Operating	
--Base	223.00 MM
-- Average annual real growth	0.00%
Production (full scale):	
Ore recovery	3.0 MDST
Ore assay	
-- Nickel	1.29%
-- Copper	1.09%
-- Cobalt	0.25%
Metals recovery	
-- Nickel	.73.4 MM lbs.
-- Copper	.60.0 MM lbs.
-- Cobalt	8.6 MM lbs.
Metals Prices:	
Price base	
-- Nickel	.$3.75/lb.
-- Copper	.$1.25/lb.
-- Cobalt	.$5.63/lb.
Annual real growth rate	
-- Nickel	0.0%
-- Copper	0.0%
-- Cobalt	0.0%

Corporate Factors:

Debt/equity 1:1
Interest rate . . . . 6.5%, real
Structure . . . . Corporation

Regulatory Factors:

Depletion
-- Determination of deposit . . . . . Foreign
-- Nickel percentage 14%
-- Copper percentage 14%
-- Cobalt percentage 14%
Tax rate 46%
Investment tax credit 10%
Revenue sharing trust fund . . . . . 0.75% of gross return

International Regime:

Revenue sharing . . . . none

2. Dealing with Uncertainty

As pointed out in the opening chapter of this study, estimation of costs and return of future deep ocean mining ventures is very susceptible to the uncertainties of the economic, technical, and political/legal environments. Many different cost estimates exist, and cost estimates are only one source of uncertainty. The technology has yet to be sustained at a commercially viable level of activity, garnering revenues from metal sales at unknown future prices, in a legal environment which could incur associated additional costs, and which in turn could induce investors to go ahead or to delay.

This study copes with uncertainties in several ways. Most basic is the design of the model itself. The model permits the easy substitution of alternate values for most parameters should future experience or research provide improved cost data. (See appendix 7 for a summary of several major user-selected variables).

Two additional means of dealing with uncertainties are treated in this section. The first uses an adaptation of the base-case, best-case, worst-case technique frequently used by investment analysts. In addition to the central values for a base set of assumptions developed in Chapter II, this section provides an up- and downside set of assumptions, changing several variables at one time. (Given the overall uncertainties referred to, these descriptions seem preferable to "best" and "worst".) The alternative scenarios, described in section IV B 4, aid in evaluating the magnitude of the project's "downside" risks as well as various possible "boons" to the project. The expected return to projects operating under these conditions is presented below in Chapter IV B 5.

The second means is the use of sensitivity analysis -- altering key variables one at a time to determine their relative impact on economic return. These analyses are presented in section IV C.

3. Some Key Variables

First, the several variables which are varied in these analyses are examined. Although the entire deep ocean mining operating environment is speculative, at least five categories of factors can be identified which are most likely to affect the return of the pioneer venture. The rationale for these selected factors and ranges for analysis around the expected values are summarized here and discussed in more detail in Appendix 7. (For a still fuller discussion, see A. Will, referenced in footnote 3.)

a) Metals Prices

Accuracy of the price forecasts for the three processed metals is vitally important to the expected return. Revenue from these metals is the only inflow of cash to the venture. Furthermore, because of the project's grand scale (an estimated 142 M total tons of metal produced annually), the impact of any inaccuracy is greatly magnified. Hence, it is valuable to examine the impact of a range of possibilities for metals prices. The basis for selecting "upside" and "downside" estimates from the available options is found in Appendix 7.

b) LOS Treaty Provisions and Status

Five aspects of the LOS Treaty are believed by the consortia to be of greatest impact to their mining prospects.[6] These are the issues of:

- -- Financial arrangements
- -- Technology transfer
- -- Production limits
- -- Minesite limitations
- -- Uncertainties posed by the structure of the authority.

The analysis uses the financial arrangements proposal found in the Informal Composite Negotiating Text, Rev. 1, in the downside case. The upside scenario considers only existing U.S. regulations. Uncertainties arising from concern over the nature of the International Seabed Authority may well be translated into delays in getting the pioneer ventures underway. Indeed, LOS concerns have already been partially credited with delays in the preproduction phase. (See Chapter II A, Figures 1-C and 1-D and associated discussion in text.) The downside scenario thus considers permitting and environmentally related delays of two years at the preinvestment and preproduction points. (Possible increased environmental control expenditures are considered below in section IV B 3 c.)

Issues relating to technology transfer, production limits, and minesite limitations do not play a role in the alternative scenarios for reasons discussed in Appendix 7 .

c) Technological Status

Technical uncertainties still exist. Some relate to presently pending choices in new systems. An example is the location of the processing plants and the minesites themselves. Location will affect the distances transversed by the ore transports, and consequently their number and size, as well as the size of the mineship's storage capacity. Such alternatives are considered in the sensitivity analysis (Section IV C) the Mining and Marine Transportation Appendices (appendices 2).

Other uncertainties are found in the mining, lifting, slurry transfer, and processing systems. Generally speaking, they could translate into decreased efficiencies, project delays, and/or increased costs. Optimistic developments in technology could result in <u>increased</u> efficiencies and <u>decreased</u> costs. (The base set of assumptions employs optimal development time.)

The downside case is assumed to decrease input tonnage by 10%, or 0.3 million dry short tons (MDST). The upside case increases input tonnage by 5% or 0.15 MDST. Associated alterations are assumed in annual operating costs. Somewhat similar decreases and increases in processing output are assumed for each case.

Project delays may result from problems in the development and implementation of the technological systems, most likely in the preproduction and investment phases. A one-year intrainvestment phase delay is introduced into the downside scenario. (Preproduction and preinvestment delays are already included in the downside case to consider consequences of international legal uncertainty.)

Capital costs estimates may suffer from two types of inaccuracies -- absolute estimating errors and misestimation of real growth. Cost estimates from eight studies of deep seabed mining suggest a reasonably broad range. (See Appendix 7). Twenty-five percent higher and lower capital costs are introduced into the downside and upside cases. Similar changes are made in operating costs.

Finally, the cost effects of how deep seabed minesites will be considered for depletion tax purposes is varied in the alternative scenarios. In the base set of assumptions, a foreign deposit percentage depletion allowance of 14% for all minerals was assumed. The downside scenario postulates a disallowance of an "economic interest" and thus no percentage depletion. The upside case considers the deposit as domestic, which enables the project to claim percentage depletion of 22% for nickel and cobalt and 15% for copper.

These sets of assumptions are summarized:

a) Upside Case

All assumptions for the upside case are identical to the base set of assumptions except as noted in table IV-3.

TABLE IV-3

UPSIDE CASE VARIABLES

Metals Prices

-- Nickel: $3.29/lb base price, +1.6T annual real growth

-- Copper: $1.31/lb base price, +1.3% annual real growth

-- Cobalt: $9.56/lb base price, +0.7% annual real growth

LOS Financial Arrangements (same as Base)

Technological Factors

-- Production: 5% increased output tonnage

-- Delays: none

Capital Costs

-- Absolute estimate: 25% less than base case

-- Growth estimate: 0

Operating Costs

-- Absolute estimate: 25% less than base case

-- Growth estimate: 0

Depletion Allowance

-- Domestic deposit

-- Percentage depletion: 22% Ni, 15% Cu, 22% Co

b) Downside

Assumptions for the downside case are also identical to the base case except as noted in Table IV-4.

TABLE IV-4

DOWNSIDE CASE VARIABLES

Metals Prices

-- Nickel: $3.46 base price, 0% annual real growth

-- Copper: $1.25 base price, 0% annual real growth

-- Cobalt: $4.67 base price, +0.3% annual real growth

LOS Financial Arrangements

-- Application Fee: $.5 MM, year 11

-- Fixed charge: $1 MM annually during production, creditable

-- Royalties: 2% first period, 4% second period

-- Profit sharing: 35%, 42.5%, 50% first period
40%, 50%, 70% second period

Regulatory Delays

-- Preinvestment: 2 years

-- Preproduction: 2 years

Technological Factors

-- Production: 10% decreased output tonnage

-- Delays: 1 year intro-investment

Capital Costs

-- Absolute estimate: 25% greater than base case

-- Growth estimate: 1% annual real growth

Operating Costs

-- Absolute estimate: 25% greater than base case

-- Growth estimate: 1% annual real growth

Depletion Allowance

-- No economic interest, no percentage depletion

4. Economic Return Projections for the Base, Upside and Downside Set of Assumptions

A project with the base set of assumptions described in Chapter II and the financial assumptions described in Chapter III yields an expected internal rate of return, in real, non-inflated terms of 9.21%. This figure is easily in excess of the "central value" discount rate of 6% referred to earlier. Table IV-5 presents the value of the project when evaluated over the selected range of discount rates.

TABLE IV-5

BASE SET APV EVALUATION

Discount Rate	16	9	8	7	6	5	4	3	2
APV($MM)	-11.8	4.6	31.0	72.3	135.9	232.5	378.3	597.6	926.9

Figure IV-1 presents the base case project's APV-discount rate graph. According to this simplified analysis, the project from an investor's perspective would appear to be profitable. If an investor's actual risk adjusted discount rate is less than 9.21%, the project would be accepted.

a) The Upside Set of Assumptions

The upside case scenario assumes that current U.S. law prevails and that the prices obtained by the venture are the more favorable of those predicted (see Table IV-3). In addition, metals recovery is increased over the expected value by 5% and all costs are 25% under predicted levels. The deposit is ruled domestic and thus a higher depreciation percentage is allowed.

Under these conditions, the mining project would expect to receive a 21.96% rate of return. Obviously, the "upside" of this project can be very profitable. Table IV-6 presents the project's estimated present values under the best case scenario.

TABLE IV-6

UPSIDE CASE APV EVALUATION

Discount Rate	10	9	8	7	6	5	4	3	2
APV ($MM)	236.7	328.0	454.7	631.4	878.9	1227.5	1721.2	2424.8	3433.6

b) The Downside Set of Assumptions

The economic return of the downside case scenario suggests the magnitude (in contrast to the likelihood) of the downside risk inherent in the project, given that several detrimental factors occur together.

The internal rate of return in this case has plummeted to -6%. It is interesting to note however, that the direct cause of this drop is the fact that only in the final year of the project (when working capital and equipment salvage value are recaptured) does the cash flow turn positive. In all years the net income is negative. It is questionable whether any corporatio would continue to operate under such conditions. Thus, the usefulness of this case is not to indicate an expected return, but to illustrate the fact that the uncertainties do present a very serious downside risk to this venture. Table IV-7 emphasizes the magnitude of this downside risk. Once again, the specific numbers obtained are not as important as understanding the seriousness of the possible project failure.

A graphical presentation of the upside downside and base sets of assumptions is found in Figure IV-2.

TABLE IV-7

DOWNSIDE CASE PROJECT APV EVALUATION

(%)

Discount Rate:	10	9	8	7	6	5	4	3	2
APV ($MM)	-333.7	-409.0	-503.7	-623.3	-775.2	-969.4	-1219.1	-1542.4	-1963.8

TABLE IV-8

PARAMETERS VARIED IN SENSITIVITY ANALYSIS

Metals Prices

-- + 25% base price, all metals
-- - 25% base price, all metals
-- + 25% base price, each metal
-- - 25% base price, each metal
-- + 1%, +2% annual real growth
-- 1980 average base price, 0% growth
-- 1980 average base price, 1% growth
-- 1980 average base price, 2% growth

LOS Treaty

-- Present treaty provisions

Technical Factors

-- - 10% output tonnage, - 5% costs
-- + 5% output tonnage, + 5% costs
-- + 10% recovery efficiency
-- - 10% recovery efficiency

Delays

-- 1 year delay, preinvestment
-- 2 year delay, preinvestment
-- 2 year delay, intrainvestment
-- 1 year delay, preproduction
-- 2 year delay, preproduction
-- 1 year delay at all three points

Capital Costs

-- Absolute estimate + 25% base, -25% base
-- 1% annual real growth

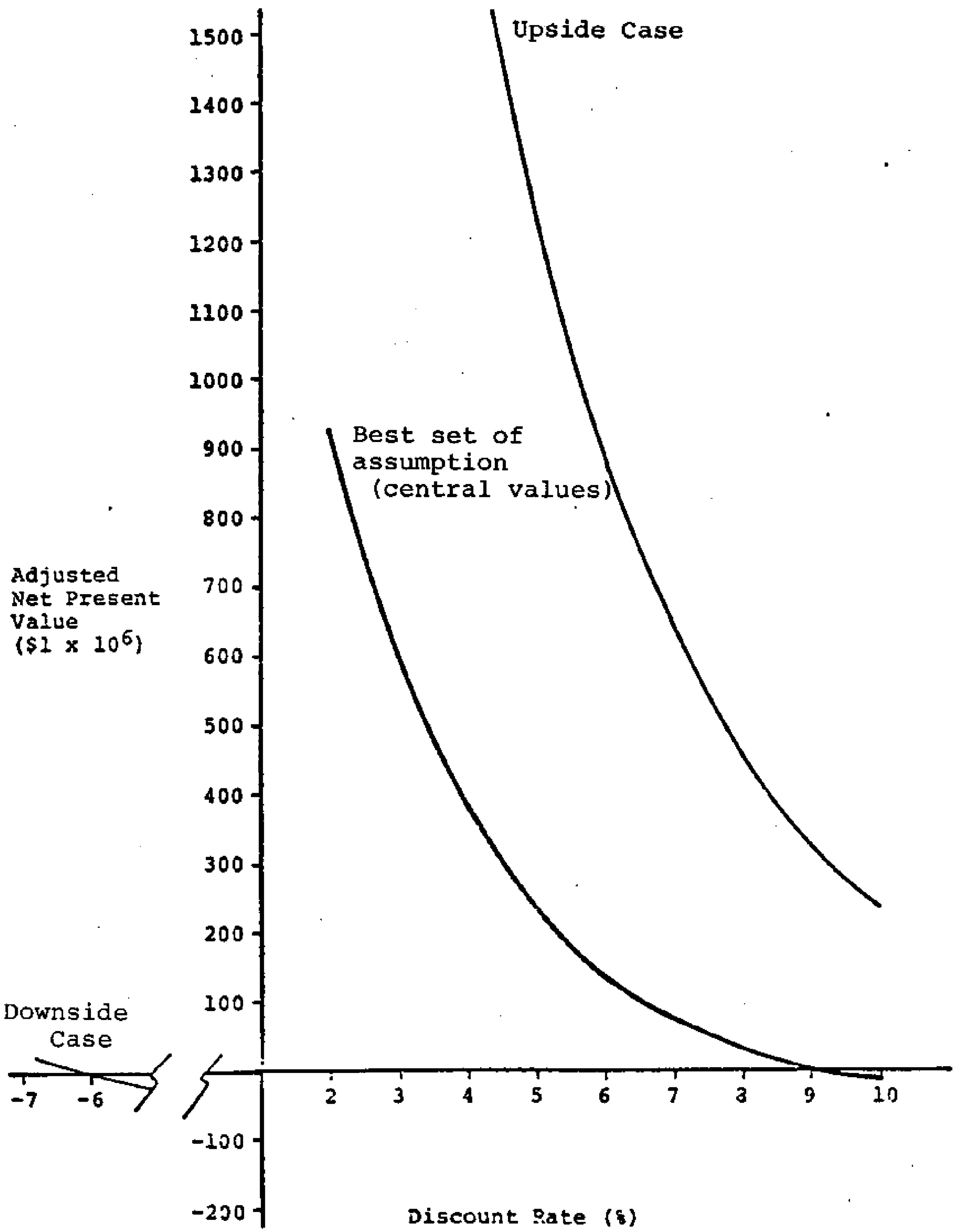
Operating Costs

-- Absolute estimate + 25% base, -25% base
-- 1% annual real growth

Depletion Allowance

-- No percentage depletion
-- Domestic deposit percentage depletion

FIGURE IV-2: ALTERNATIVE SCENARIOS-BEST, UPSIDE, DOWNSIDE, WORST, AND BASE CASES



C. Sensitivity Analysis

It is useful to understand the degrees of influence exerted by individual environmental factors represented by the variables discussed in the alternative sets of assumptions. After examining environmental factors, additional factors concerning corporate or financial structure and tax accounting practices are examined for their individual impacts on economic return. The values given the variables in these analyses are listed in table IV-8.

Meaningful sensitivity analysis begins by determining a factor's likely variation. Theoretically, it would be ideal if, for each factor, a variation exhibiting an equal probability of occurrence could be identified. If this were possible, then all factors could be rank-ordered by "degree of influence." However, the speculative nature of this venture prevents highly accurate estimation of the corresponding probability distributions. Thus basically conservative estimates of the variability of these parameters are considered. The probability of occurrence is not attached to these estimates.

1. Metals Prices

A general measure of the influence of metals prices upon profitability is obtained through variation of the level of gross revenue. A twenty-five percent error in revenue estimation is entirely plausible. This is evidenced by the range of price forecasts described in Section II 6. Sensitivity analysis of plus or minus 25% conducted on gross revenues reveals the following APV range in Table IV-9.

TABLE IV-9

APV EVALUATION FOR REVENUE ESTIMATION VARIATIONS

Discount Rates (%)	10	9	8	7	6	5	4	3	2
+25% GR	66.2	105.9	163.3	246.3	366.0	539.0	789.6	1153.3	1684.7
-25% GR	-122.2	-133.7	-143.4	-149.1	-147.5	-133.2	-97.7	28.0	96.5

APV($MM)

The resultant IRR's were 13.91% and 2.74% for the increased and decreased revenues, respectively. As expected, the economic return is highly sensitive to the level of gross revenue. This is further illustrated by Figure IV-3, which displays these effects graphically.

The gross revenue analysis in itself is not very informative. Disaggregating the gross revenue into the individual metals' revenue streams provides additional understanding. Table IV-10 presents the results of a 25% variation of each metal's revenue. Table IV-11 compares the internal rates of return for the individual metals. Figures IV-4 to IV-6 present these data graphically. As can be seen, the revenue obtained from nickel is particularly influential to the project's rate of return. This result is to be expected, as nickel is approximately 52% of product metal by weight at full production capacity. Copper and cobalt are 42% and 6% by weight, respectively. Because of price differentials however, nickel contributes over 65% of total revenue (in the base case) while copper, cobalt, and secondary products contribute 18%, 11%, and 5% respectively. It should be noted, however, that the contribution-to-revenue ratio shifts significantly based upon 1980 metals prices (45%, 11%, 39%, 5% for nickel, copper, cobalt, and secondary products, respectively). Prevailing opinion is that the exaggerated cobalt price will not be sustained, but will soften somewhat.

The base set of assumptions assumes no real growth of metals prices. However, most resources have exhibited positive real growth over time, and it is therefore reasonable to assess the impact of such growth. The effects of 1% and 2% annual real growth in metals revenue is presented in Table IV-12 and Figure IV-7. A 1% annual real growth rate increases the IRR from 9.21% (baseline) to 14.91%, while a 2% rate of growth further increases the return to 19.81%. Real growth in metals prices is thus extremely influential on economic return to the project. The rank ordering of metals in terms of importance is identical to

FIGURE IV-3: TWENTY-FIVE PERCENT GROSS REVENUE VARIATION

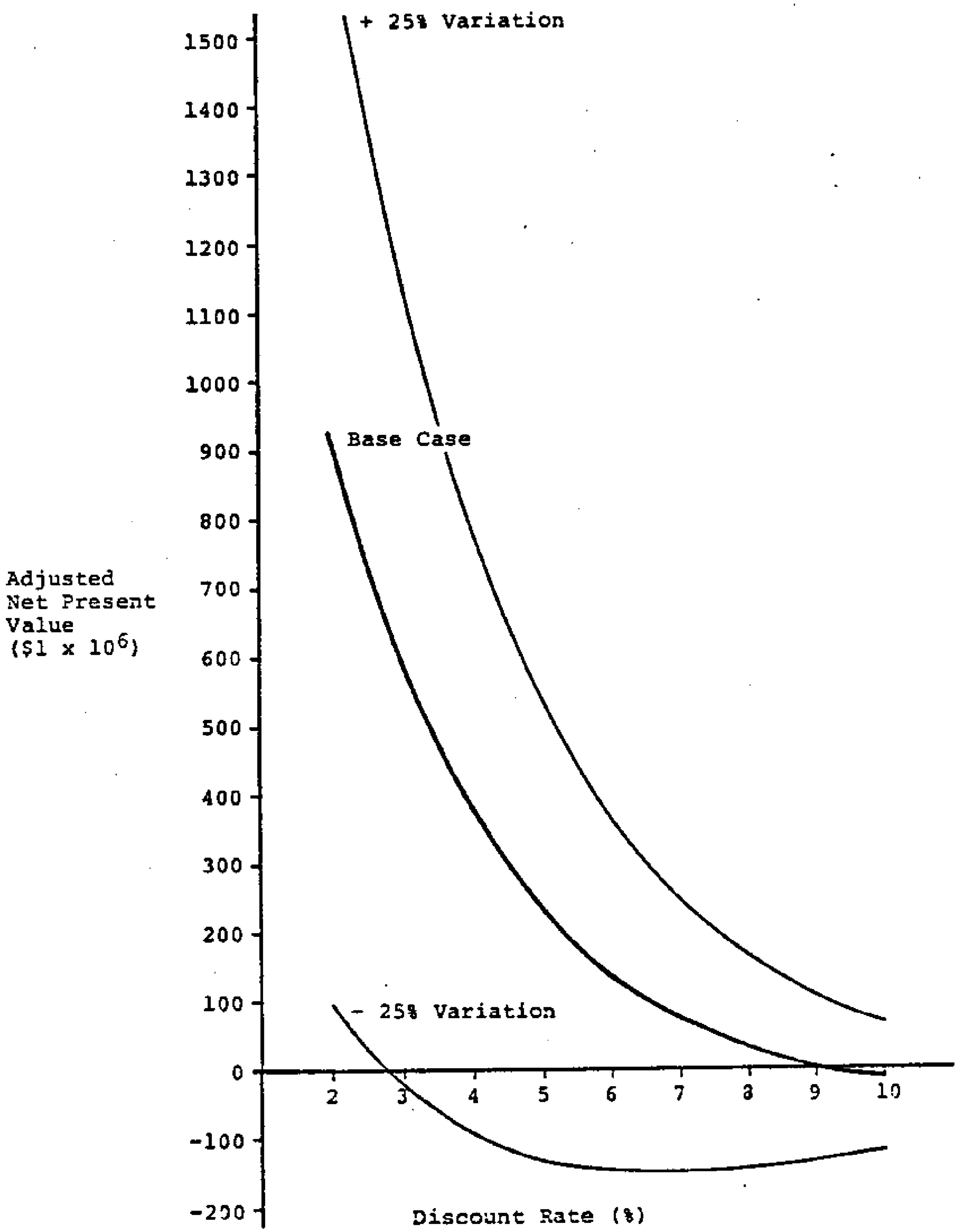


TABLE IV-10: APV's FOR INDIVIDUAL METAL REVENUE VARIATION ($MM)

	Discount Rates (%)								
	10	9	8	7	6	5	4	3	2
+25% Ni	43.9	76.8	125.2	196.0	299.4	450.0	669.8	991.2	1462.7
-25% Ni	-86.0	-89.0	-87.9	-79.8	-60.2	-22.3	44.5	156.4	338.5
+25% Cu	3.6	24.5	56.9	106.3	180.7	291.9	457.8	704.7	1072.3
-25% Cu	-27.9	-16.2	4.1	37.2	89.6	171.2	296.6	487.7	778.1
+25% Co	-2.0	17.3	47.6	94.0	164.4	270.4	428.9	665.8	1019.4
-25% Co	-21.7	-8.2	14.3	50.5	107.2	194.5	327.5	529.3	834.3

TABLE IV-11: IRR's FOR INDIVIDUAL METAL REVENUE VARIATION

Case	IRR
+25% Ni	12.44%
-25% Ni	4.64%
+25% Cu	10.21%
-25% Cu	8.19%
+25% Co	9.86%
-25% Co	8.59%

FIGURE IV-4: TWENTY-FIVE PERCENT NICKEL PRICE VARIATION

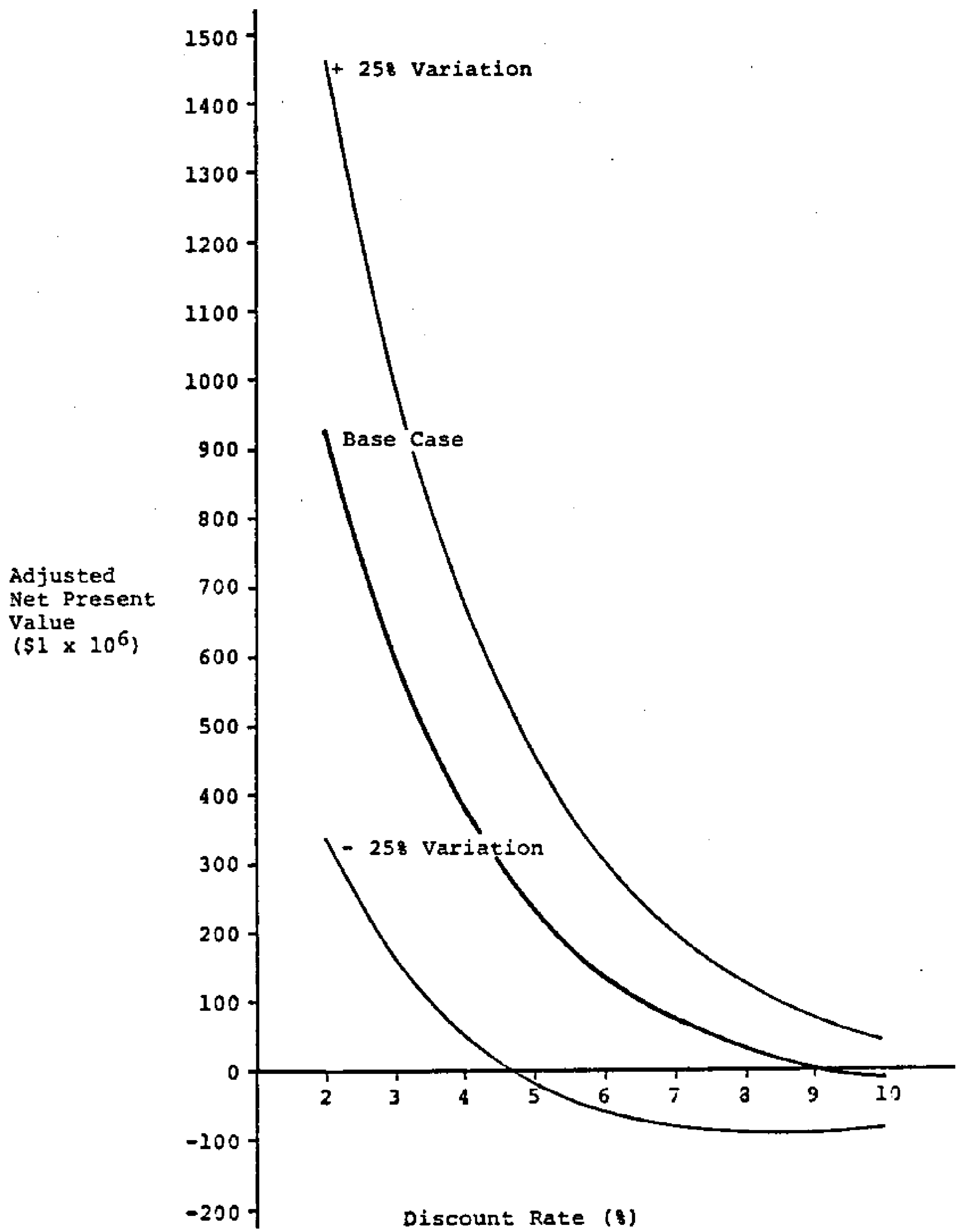


FIGURE IV-5: TWENTY-FIVE PERCENT COPPER PRICE VARIATION

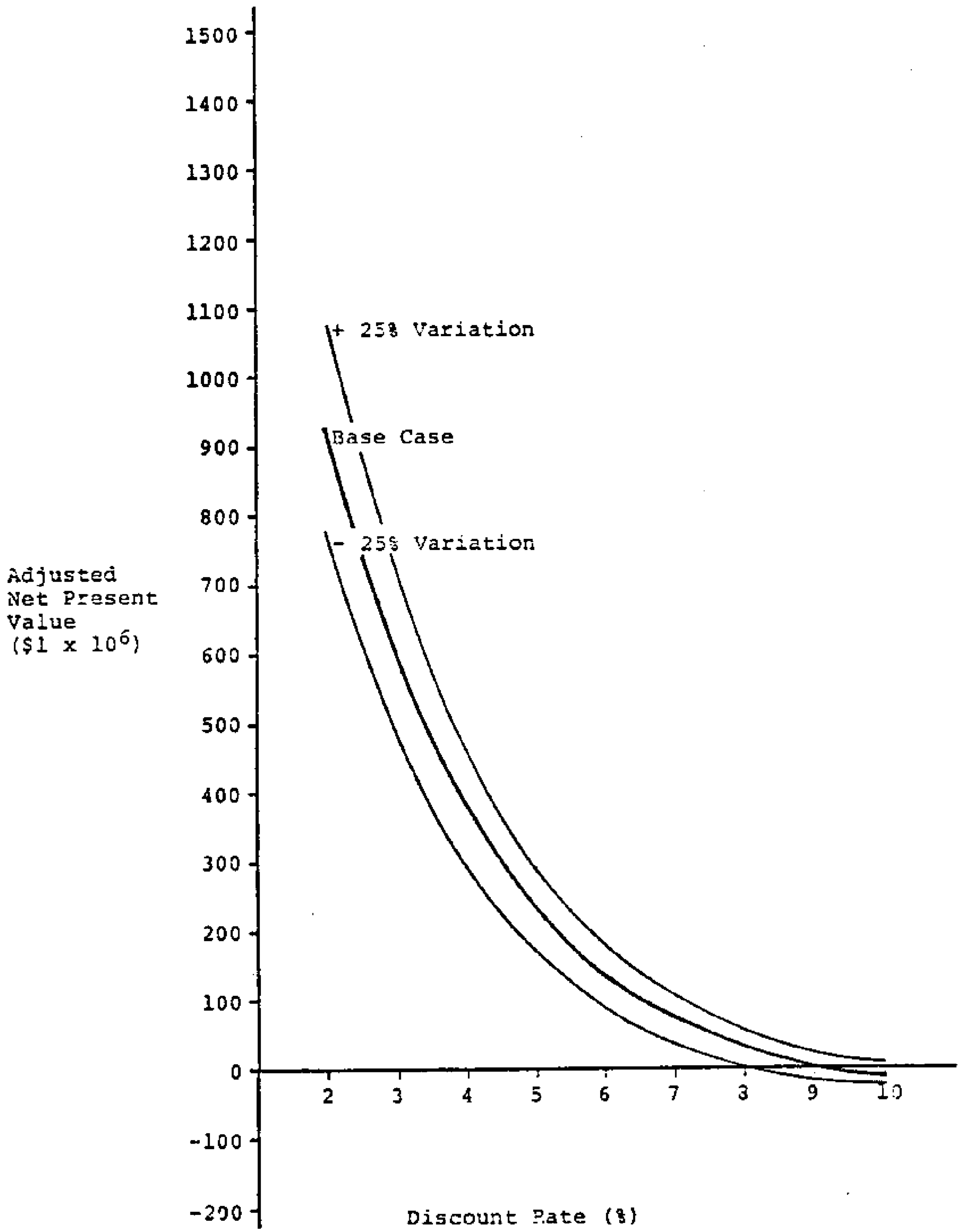


FIGURE IV-6: TWENTY-FIVE PERCENT COBALT PRICE VARIATION

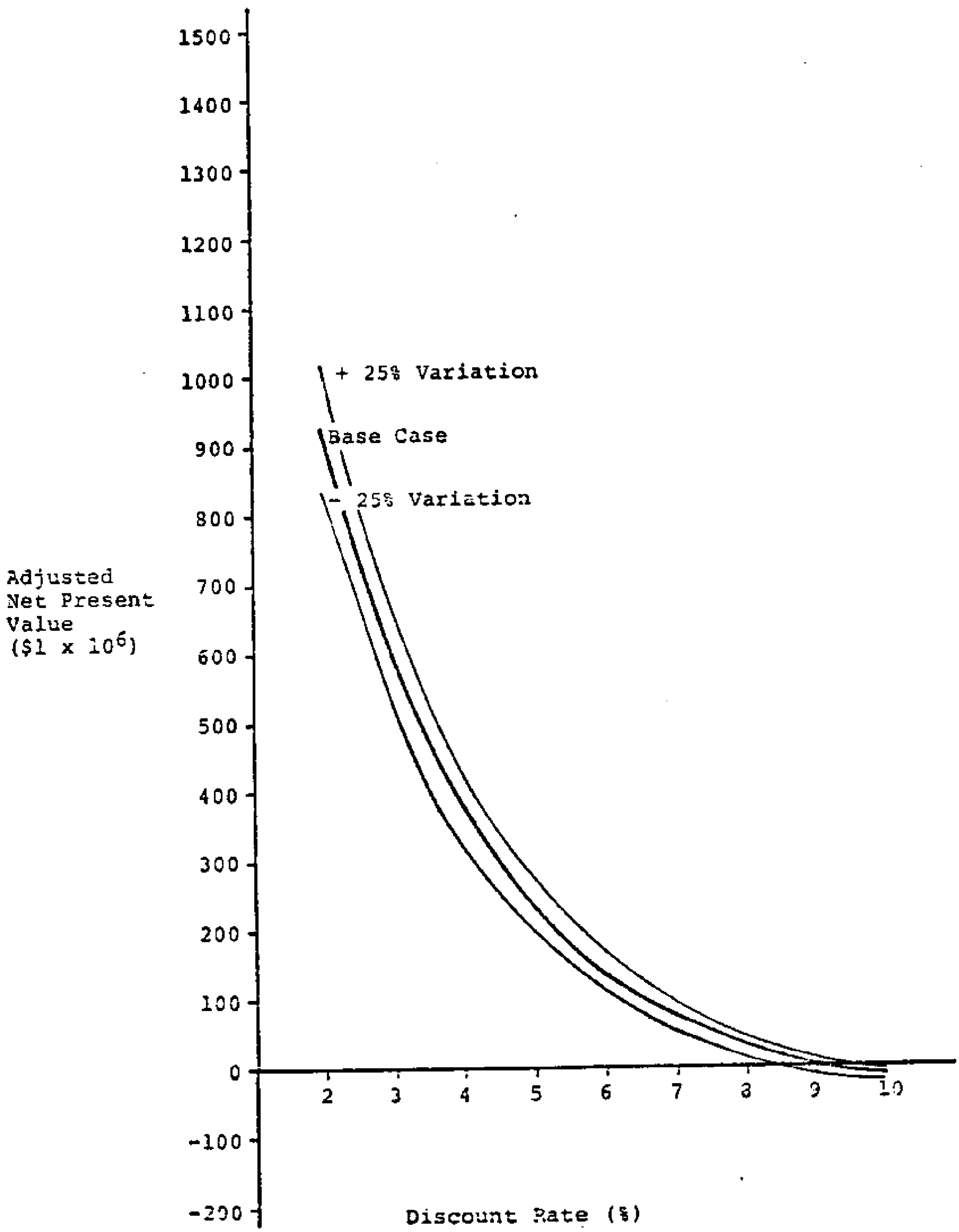
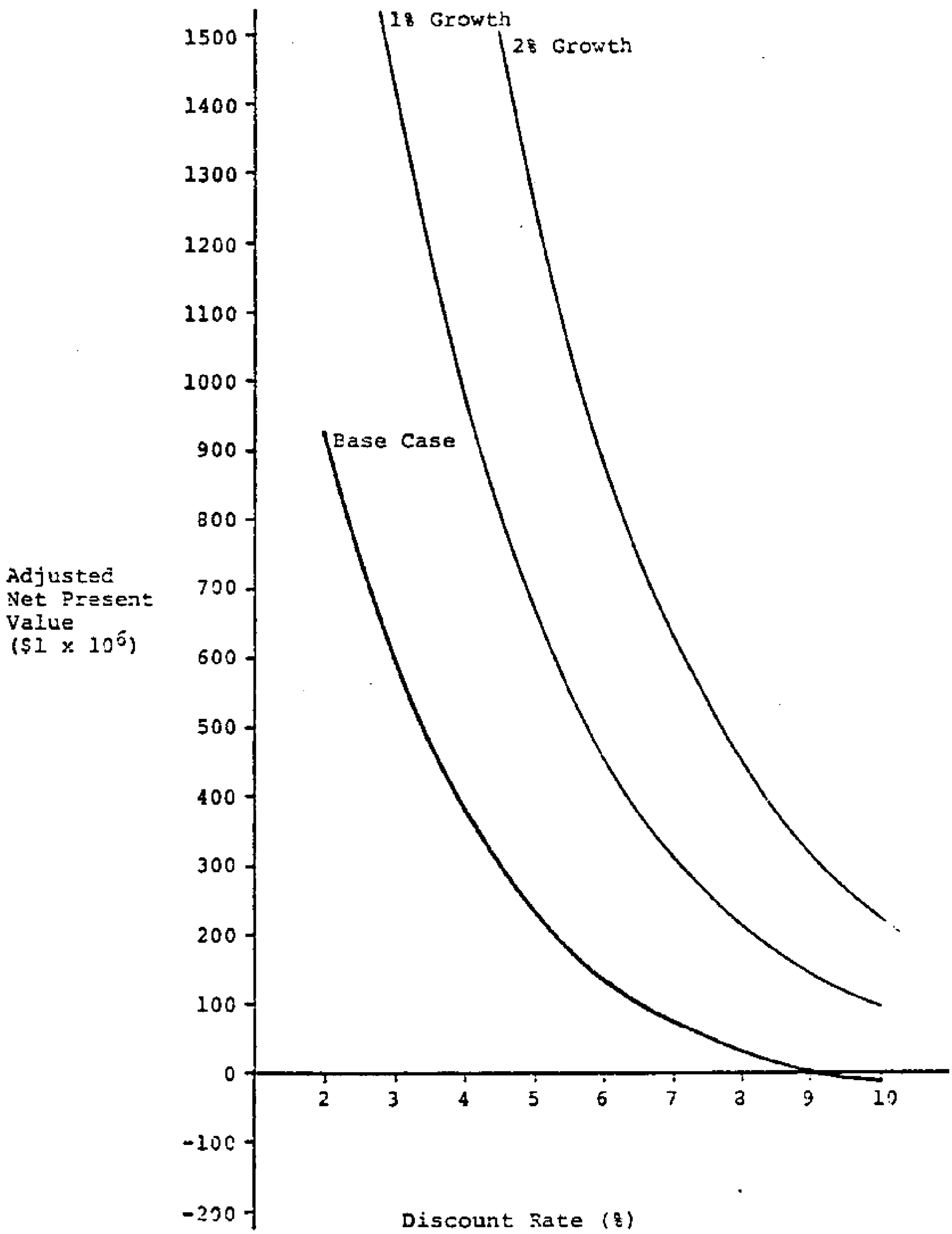


TABLE IV-12: APV's FOR REAL REVENUE GROWTH ($MM)

Discount Rates (%)

	10	9	8	7	6	5	4	3	2
1% Annual Growth	91.6	140.9	211.8	313.9	461.0	673.1	980.1	1425.9	2076.3
2% Annual Growth	223.5	316.1	446.3	629.7	889.3	1258.4	1785.8	2543.7	3639.1

FIGURE IV-7: REAL GROWTH IN METALS PRICES



that discussed in reference to the individual revenue streams.

The 1980 average prices for nickel, copper, and cobalt were $3.33, $1.01, $25.00 (U.S.), respectively. Based upon trend line estimates, these prices might actually be outliers (this is particularly true for the inflated price of cobalt); however, because tomorrow's price is, in part, a function of the current price, it is useful to examine the effects of using 1980 averages as price bases. Table IV-13 presents these results. The internal rates of return for 0%, 1%, and 2% real growth are 14.51%, 19.61%, and 24.26%, respectively. This very favorable increase in return is largely due to the greatly increased 1981 cobalt price.

2. The International Legal Regime

The current version of the LOS Treaty is a valuable reference point when considering the impact of international law. It is doubtful that a more severe treaty will be adopted, and yet only months ago this version was considered likely to be ratified. When investigating the subsequent economic impact of the currently proposed financial arrangements on a deep ocean mining venture, it is thus particularly appropriate to view the return as a continuum of results ranging from no treaty to the present treaty form. Table IV-14 and Figure IV-8 present the APV's for the range of asset discount rates. The internal rate of return for the venture in this situation is 8.19%, a drop of slightly over 1 percentage point from the base set of assumptions Total nominal payments to the Seabed Authority over the life of the project equal approximately $437 million. Thus, although the treaty is influential to the project return, many other uncertainties in the business environment pose greater threats. Only in the case of much more severe treaty conditions would the venture suffer seriously from treaty enactment.

TABLE IV-13: ADJUSTED PRESENT VALUES, 1980 AVERAGE PRICE AS BASE ($MM)

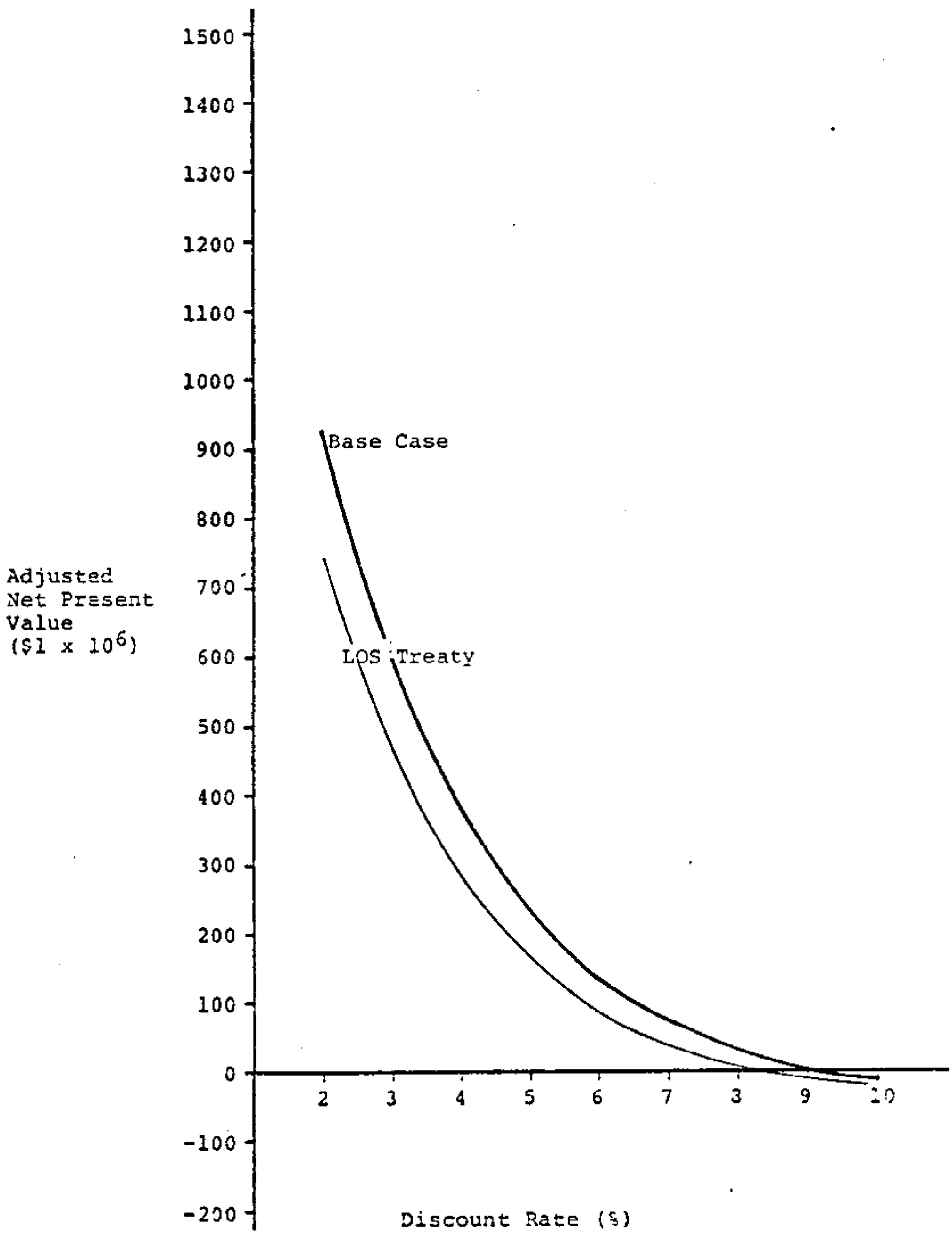
Discount Rates (%)

	10	9	8	7	6	5	4	3	2
0% Annual Price Growth	77.6	120.7	182.7	271.8	400.0	584.5	850.8	1236.8	1798.3
1% Annual Price Growth	204.0	288.0	405.7	570.9	803.9	1134.0	1604.0	2276.9	3245.9
2% Annual Price Growth	372.8	512.6	706.3	916.2	1354.0	1886.1	2639.9	3714.4	5256.4

TABLE IV-14: LOS TREATY SENSITIVTY ANALYSIS, APV's (%)

Discount Rate:	10	9	8	7	6	5	4	3	2
APV ($MM)	-26.5	-15.1	4.4	36.2	86.5	164.5	284.0	466.0	741.9

FIGURE IV-8: EFFECT OF CURRENT LOS TREATY



3. Technological Factors

Technological problems can be categorized according to three types of effects: efficiency effects, delays, and cost effects.

Efficiency effects are examined through two hypothetical circumstances. First, input efficiencies may cause altered amounts of ore to be processed without commensurately increased operating costs. As outlined in Appendix 8, the two input efficiency situations considered are: (1) a 10% decreased output tonnage and 5% decreased operating costs; and (2) 5% increased tonnage and 5% increased operating costs. The decreased input tonnage decreases IRR only about 1.7%. The increased input tonnage results in only a slight increase in IRR of approximately half a percent.

Output tonnage efficiency effects, which are not expected to be accompanied by cost effects, are investigated through a hypothetically altered recovery efficiency. A plus or minus 10% output tonnage is assumed in this case. The internal rate of return, as expected, is altered more significantly due to the lack of countervailing cost effects. The IRR's now equal 11.31% and 6.64% in the case of increased and decreased output tonnage, respectively. Table IV-15 summarizes the full APV range for these efficiency effects. In addition, Figure IV-9 expresses these results graphically.

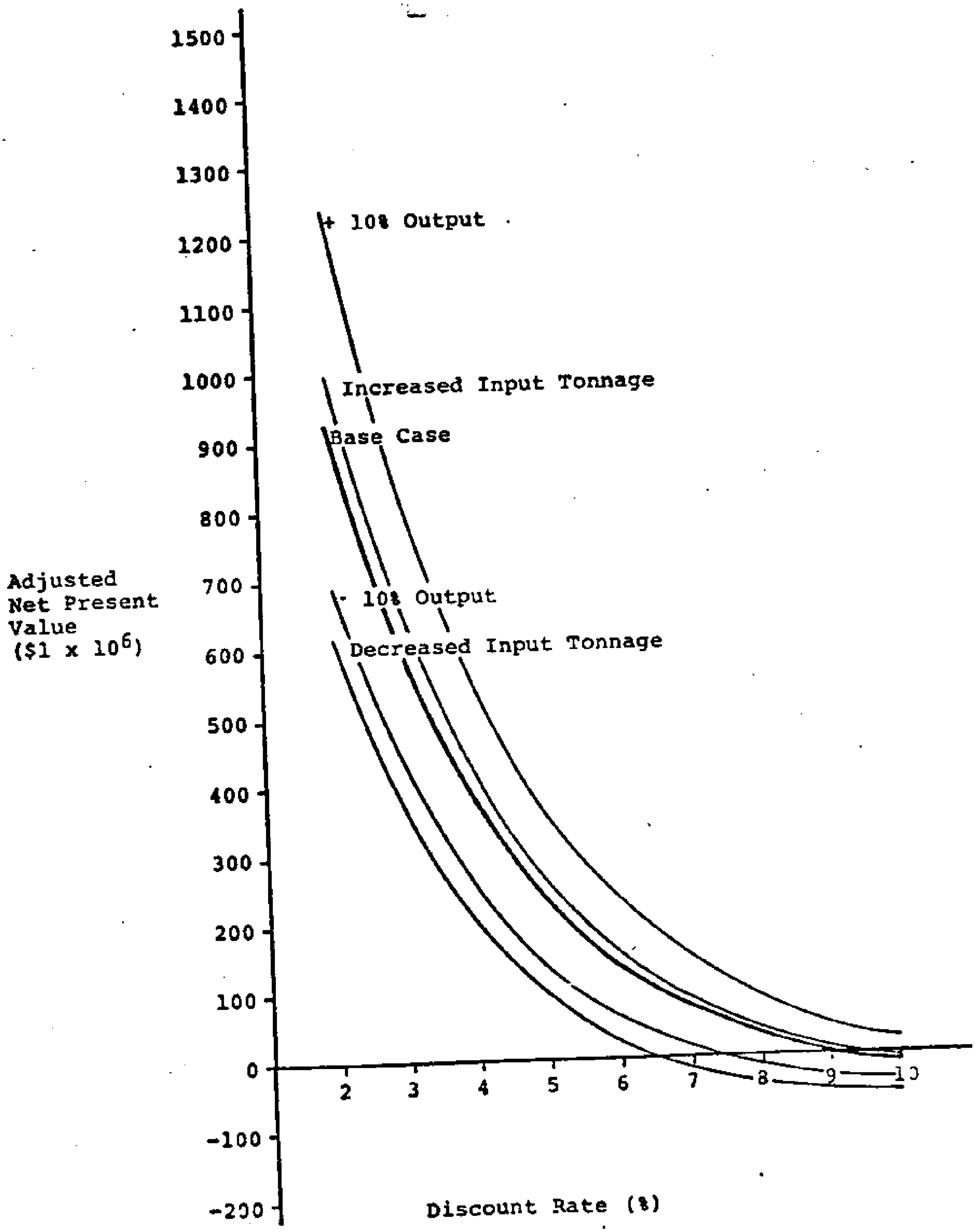
Delays in the mining project due to technological causes are considered at three stages (see chapter II c). The effects of these delays on the project's economic return are as follows:

One-year preinvestment delay, IRR = 8.99%
Two-year preinvestment delay, IRR - 8.79%
One-year intrainvestment delay, IRR = 8.99%
Two-year intrainvestment delay, IRR = 8.79%
One-year preproduction delay, IRR = 7.29%
Two-year preproduction delay, IRR = 6.64%
One-year delay at all three junctures, IRR = 7.04%

TABLE IV-15: APV's RESULTING FROM TECHNOLOGICALLY-INDUCED EFFICIENCY EFFECTS ($MM)

Discount Rate (%):	10	9	8	7	6	5	4	3	2
+5% Input Tonnage; +5% Op. Costs	-4.9	13.7	43.0	88.3	157.2	261.1	417.0	650.4	999.4
-10% Input Tonnage; -5% Op. Costs	-36.7	-27.6	-11.0	17.3	63.2	135.9	249.1	423.4	690.2
+10% Output Tonnage	20.9	47.0	86.2	144.7	231.4	359.4	548.2	826.7	1238.4
-10% Output Tonnage	-55.0	-49.0	-36.1	-12.2	28.4	94.7	199.8	364.2	618.2

FIGURE IV-9: EFFECTS OF TECHNOLOGICALLY-INDUCED EFFICIENCY FACTORS



Because of the pattern of capital build-up during the investment period, there is little economic difference between a preinvestment delay and an intrainvestment delay. The most significant influence is exerted by a delay at the preproduction point. The reason for this is that at the preproduction stage, all capital expenditures have been made and no revenues have begun to accrue. A two-year delay at this stage is most damaging and decreases return even more significantly than three single-year delays. Table IV-16 presents the results from the economic evaluation of delays across a spectrum of selected discount rates.

4. Project Costs

Technological problems may also result in capital and operating cost overruns. The influence of these overruns is the same as that caused by misestimation of absolute costs. Thus, these factors are considered in this and the following section.

Similarly to metals prices, estimated project costs are varied from actual costs in two ways. First, in order to examine the sensitivity of profitability to absolute cost accuracy, both capital and operating costs are varied 25%. Next, to test the effect which this assumption exerts on projected return, a 1% annual real growth rate was also factored into the sensitivity analysis. The base, or central, values assume no real growth in costs. The results of these cost analyses are presented in Table IV-17. Figures IV-10 and IV-11 illustrate these results graphically.

In general, operating costs affect return more dramatically than do capital costs. As might be expected, an absolute estimating error in capital costs affects return more significantly than does annually compounded growth in capital costs. Because operating costs are spread over a greater period, the reverse tends to be true: compounded growth tends to affect return more significantly than does a misestimation in absolute accuracy. The internal rates of return for this analysis are as follows:

+ 25% Capital Costs, IRR = 7.29%

- 25% Capital Costs, IRR = 11.26%

1% Capital Cost Growth, IRR = 7.04%

+ 25% Operating Costs, IRR = 5.49%

- 25% Operating Costs, IRR = 12.21%

1% Operating Cost Growth, IRR = 3.89%

An illustration of the way project costs can vary according to different assumptions as to transportation of ore, for example, is provided by examining the projections for the draft of the ore discharge terminal port and the distance from that port to the minesite. In the base set of assumptions, it is assumed that the distance between port and minesite is 1,750 miles and that the port draft is 40 feet. Four ore transport ships of 44,700 DWT are used, at a projected capital cost of $195.5 m and annual operating cost of $22.0 m.

If a port depth of 50 feet is assumed, much larger ships of nearly 90 DWT may be assumed, with a capital cost of $139.2 m. and operating cost of $15.4 m. In contrast, if the draft restriction is lowered to 35 feet, and the distance between port and mineship is increased to 2500 miles, six vessels of 41,400 DWT are required with projected capital cost of $292.7 m. and annual operating costs of $32.9 m.

TABLE IV-16

ADJUSTED PRESENT VALUES FOR TECHNOLOGICALLY-INDUCED DELAYS ($M)

Discount Rate (%)	10	9	8	7	6	5	4	3	2
One-year delay, Preinvest.	-14.7	0.0	24.2	62.8	123.2	216.2	358.3	574.6	903.2
Two-year delay, Preinvest.	-17.2	-4.1	18.0	54.2	11.5	201.0	339.6	553.0	880.9
One-year delay, Intra invest.	-14.7	0.0	24.2	62.8	123.2	216.2	358.3	574.6	903.2
Two-year delay, Intrainvest.	-17.2	-4.1	18.1	54.2	111.5	201.0	339.6	553.0	880.8
One-Year dealy, Preprod.	-47.3	-38.3	-20.8	10.2	61.6	144.3	274.7	477.9	792.1
Two-year delav, Preprod.	-62.0	-56.1	-42.2	-15.4	31.3	109.3	235.3	435.7	750.7
Three one-year delays	-46.5	-40.1	-26.1	0.1	45.6	121.3	244.2	440.8	752.1

TABLE IV-17

PROJECT COST SENSITIVITY ANALYSIS -

APV's ($MM)

	Discount Rate (%)								
	10	9	8	7	6	5	4	3	2
CAPITAL COSTS									
+25%	-52.9	-42.8	-23.4	10.4	65.8	154.2	292.3	505.6	832.4
-25%	17.2	39.1	72.0	121.0	193.4	300.2	457.4	689.1	1031.0
1% Growth	-57.3	-48.2	-30.3	1.3	53.6	137.5	268.8	471.9	783.3
OPERATING COSTS									
+25%	-75.0	-74.3	-68.0	-52.7	-23.2	28.5	114.6	253.6	474.2
-25%	35.4	65.2	109.2	173.8	268.5	407.0	609.6	906.6	1342.9
1% Growth	-92.2	-97.8	-100.5	-97.8	-86.0	-59.5	-9.4	78.0	223.7

FIGURE IV-10: ABSOLUTE COST VARIATION

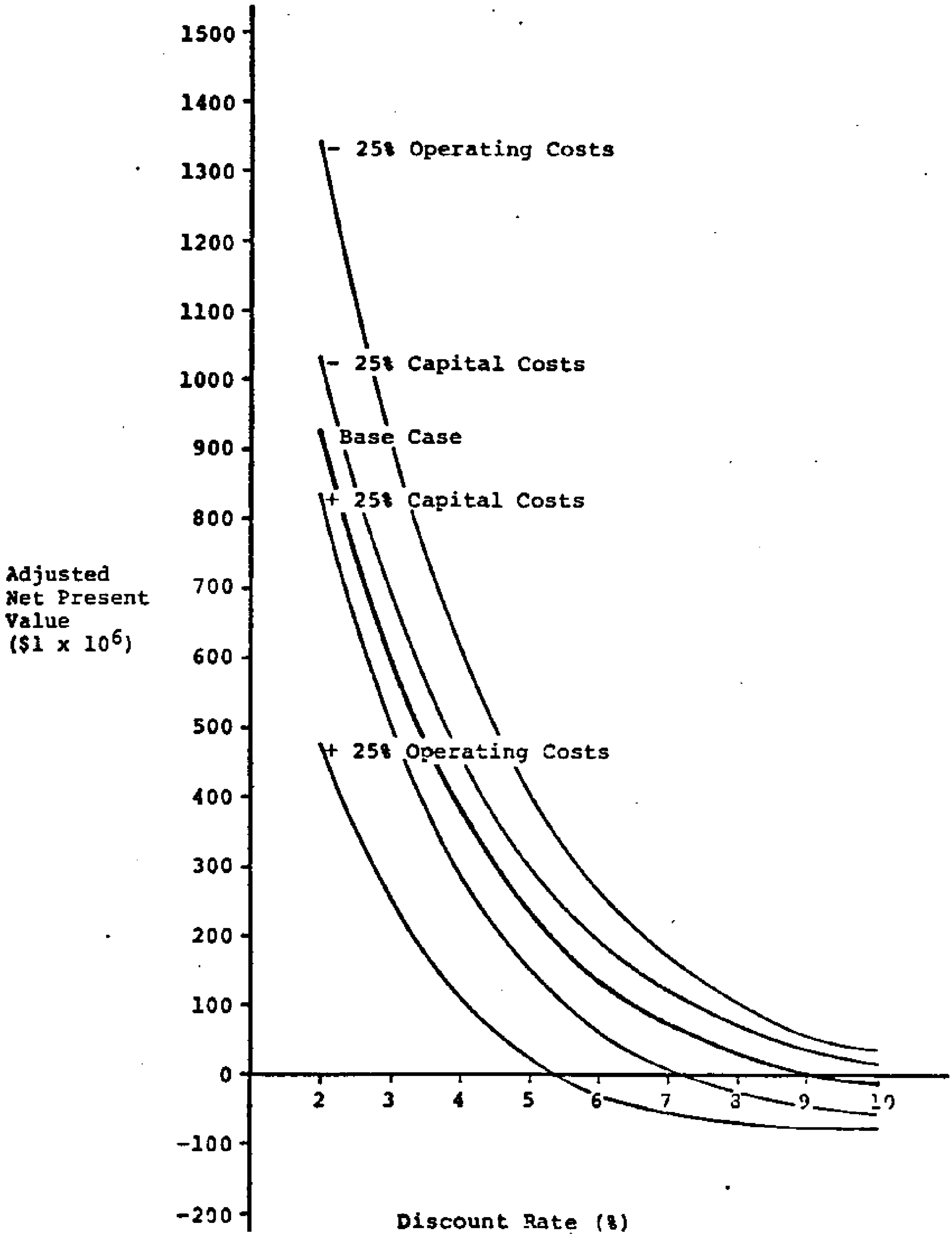


FIGURE IV-11: REAL COST GROWTH

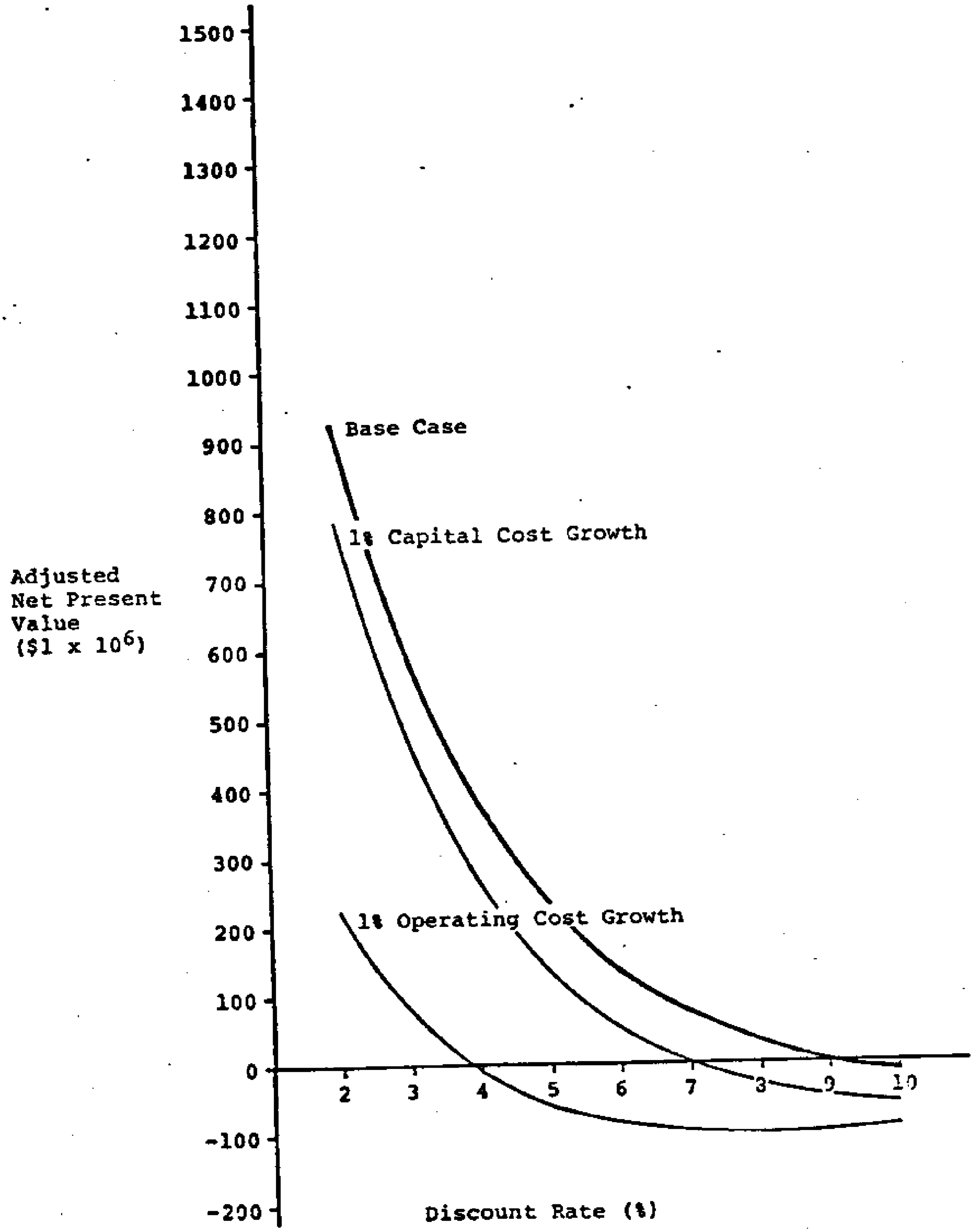


Table IV-18: DEPLETION ALLOWANCE SENSITIVITY ANALYSIS, APV's ($MM)

	Discount Rates (%)								
	10	9	8	7	6	5	4	3	2
No Depletion	-19.0	-5.1	18.0	54.6	111.7	199.3	332.4	533.6	837.3
Base Case (14%)	-11.8	4.6	31.0	72.3	135.9	232.5	378.3	597.6	926.9
Domestic Dep. (22%, 15%,22%)	-9.9	7.2	34.7	77.6	143.3	243.0	393.4	619.3	958.3

5. Depletion Allowance

Variation of the depletion allowance affects return on the project only slightly. When no percentage depletion is allowed, the internal rate of return is 8.74% (as compared to 9.21% in the base set with foreign deposit depletion allowance). If the seabed deposit is treated as a domestic deposit (and 22% depletion is allowed for nickel and cobalt, 15% for copper), the IRR increases 0.15% to a value of 9.36%. This illustrates vividly the significance of the more influential factors such as metals prices and operating costs. In this instance, federal tax policy is not nearly as effective as price constraints would be. The range of values at various discount rates for the depletion sensitivity analysis is presented in Table IV-18.

6. Corporate Structure and Related Accounting Practices

The model's basic set of assumptions describe a project standing on its own for accounting purposes even though it is created and owned by the members of the consortium. This assumption may distort the reality of corporate project development practice in at least two ways: in the accounting for tax purposes of preparatory expenses and in the taking of tax writeoffs once commercial deep ocean mining is underway.

In the central values case, the IROR figure of 9.21% is based upon a discounted cash flow (DCF) calculation which discounts future cash outlays and inflows back to the time of writing, 1981. In accordance with current best financial analysis practice, costs up to this time are "sunk", that is, they are considered by the company to be written off, and have in fact been taken by the companies as cost of doing business expense for tax purposes.

Some industry analysts suggest that in actuality, members of consortium will continue to expense on their own books the preproduction costs of the project up to the time of the final decision to go into commercial production (in the model, the final go-no go decison in year 16). The project is then incorporated as a separate entity, consortium members receiving stock representing contributions which approximate the accrued sum of the preproduction costs. These are then amortized over the life of the newly incorporated project, in accordance with currently approved tax practice. From a financial analysis perspective, the approximate equivalent of such accounting treatment would be to sink all costs up to the point of the final go - no go decision and to discount the value of the future cash flow back to that point, e.g. year 16 in the MIT model. When this is done, holding all other things equal, an IROR of 11.01% results.

(Keeping all other assumptions the same, a DCF calculation taking costs back to the origin of the project, year 1 on the Figure 1 timeline (see section II) and including all future preparatory costs to come, would produce an IROR of 7.44 %, reflecting a combination of both the inclusion of costs between year 1 and year 11 and the further future distancing of the bulk of the P & E, R & D, and capital costs.)

Thus, by use of more sophisticated tax accounting assumptions, changes in the economic return analysis can be readily affected.

7. Financial Structure

Changes in the financial structure of the project will obviously provide different economic results for the investors. Three are illustrated here.

The basic set of assumptions employs a real interest rate of 5%. As discussed in section III.B, this rate is based on an assumed real cost of capital of say 3%, and a risk premium of 2%. Implicit in such a risk premium is the assumption that the project has strong backing of, and perhaps even recourse to, the consortium members as corporate parents. It might equally be assumed that the project really stands on its own in all respects pertinent to creditworthiness, in which case a somewhat higher risk premium might reasonably be assumed. The IRR figures resulting from different real interest rates, using all the same other values for the basic set of assumptions are shown in Table IV-19.

TABLE IV-19

Effect of Different Interest Rates

Interest Rate	IRR	10	9	8	7	6	5	4	3	2
5 (base case)	9.21	-11.8	4.6	31.01	72.34	135.9	232.49	378.29	597.56	926.87
6	9.01	-15.51	0.07	25.46	65.54	127.53	222.15	365.48	581.65	907.03
7	8.74	-19.78	-5.18	19.00	57.56	117.63	209.86	350.15	562.46	882.91
8	8.49	-23.90	-10.21	12.83	49.97	108.27	198.27	335.76	544.54	860.52

Second, the basic assumption in the analyses of this chapter is that the project's debt/equity ratio is 1:1, half of the required funding coming from borrowing. The proportion of debt could be higher, so long as the cash flow is sufficient to service the borrowing, or it could be lower. A 2:1 debt/equity ratio (i.e. 67% debt) results in a pretax IRR of 11.91% as contrasted with 11.41% for a 1:1 debt structure and 10.26% for an all-equity, no-debt situation.

Finally, the volume and financing arrangements for working capital illustrate once more how details of the financial structure may affect the economic return analysis of the project. In the basic set of assumptions, working capital of $75 m. is provided as required at the outset of the project, and taken out at its end. This figure may be low. Cash flow working capital requirements may vary from time to time depending on the other sources contributing to cash flow. Working capital requirements may be met in part by temporary borrowing as well as by permanent equity or debt components of the financial structure. When the working capital figure is increased to illustrative purposes more than doubled to $175 m., the resulting IRR is 8.69%, a change of .52 points.

NOTES

Chapter I

1. The first version of the model was reported in Nyhart et al. A Cost Model of Deep Ocean Mining and Associated Regulatory Issues, MIT Sea Grant Program MITSG 78-4, March 1978. For accounts of the use of the initial version in the Law of the Sea negotiations, see R. Katz, "Financial Arrangements for Seabed Mining Companies: An NIEO Case Study", 13 Journal of World Trade Law 218 (1979); H. Raiffa, The Art and Science of Negotiation, Ch. 18, Cambridge, Mass., Harvard University Press,1982; "Computer Model Aids Law of the Sea Mining Negotiations", INFOWORLD, Vol. 5, No. 20, April 1982; J. Sebenius, Agreements and Disagreements: Negotiation Analysis and the Law of the Sea, Cambridge, Mass., Harvard University Press (forthcoming).

2. See L. Antrim, and J. Sebenius, "Incentives for Ocean Mining Under the Convention", Ch. 6 in B. Oxman, D. Caron, and C. Buderi, eds., Law of the Sea: U.S. Policy Dilemma, San Francisco, Institute for Contemporary Study 1983 for a comparative analysis of the two versions and an evaluation of the effects of design and cost changes made.

3. The M.I.T. project team over a year-and-a-half period collaborated with three consultants under contract to the office of Ocean Mining and Energy, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. They were: Benjamin V. Andrews, Manalytics, Inc.; Francis Brown, EIC; John E. Flipse, Texas A & M University. Each submitted cost estimations to NOAA covering one or more of the three major technical sectors -- ore transportation, processing, and mining. The M.I.T. project team drew extensively on these studies and gratefully acknowledges their authors' aid and assistance in preparation of our own studies. In cases described in the appropriate sections of this study, these data

were used directly, as were data from other industrial sources in the general literature. In other cases, these data have been used as a parallel check on estimations derived from sizing analyses done by the project team.

In addition, the consultants, NOAA's Office of Ocean Minerals and Energy, and the project team collaborated over many months to arrive at a consensus concerning a feasible sequence of events as a pioneer venture moves from its present state to commercial production. These events are presented at various places throughout the study. They are presented in a single cohesive form in J.D. Nyhart, M.S. Triantafyllou, J. Averback and M. Gillia, Toward Deep Ocean Mining in the Nineties, MIT Sea Grant Program, MITSG 82-1, April 1982.

The M.I.T. project team benefited from and enjoyed working with the consultants as well as with members of the NOAA office. Nonetheless, the team bears the responsibility for estimates and statements here that are not otherwise noted.

4. For further details of the engineering aspects of the mining and transportation sectors, see the several appendices, and see M.S. Triantafyllou, A. Bliek, and R. Nakagama, Engineering Aspects of Deep Ocean Mining, MIT Sea Grant Program (to be published).

5. Loren Dworin, "The Taxation of Deep Seabed Mining". Report to U.S. Treasury, Febr., 1979.

6. Will, Allan, infra note 3 for chapter IV.

Chapter II

1. See Walter Kollwentz, "Prospecting and Exploration of a Manganese Nodule Occurrences", in Metallgesellschaft AC -- Review of the Activities, Edition 18, pp. 18-19.

2. Amor L. Lane and M. Karl Jugel, The Management of Deep Seabed Mining", Managing Natural Ocean Resources, II Ocean Policy Studies 1,31, Center for Ocean Law and Development, U. Va. Law School, 1979.

3. The subsectors shown in Table II-9 and in Appendix 5 differ from those shown in Appendix 8. The former follow equipment groupings that facilitate cost estimation, while the latter follow depreciation groupings that are appropriate for tax calculations.

Chapter IV

1. S.C. Myers, "Interactions of Corporate Financing and Investment Decisions -- Implications for Capital Budgeting", Journal of Finance 29: 1-25, March 1974.

2. The graphs were also used in the MIT project's 1978 study, supra, chapter I, note 1.

3. The analyses in this section, with a few exceptions, were completed during Spring 1981, by Allan Will, then a Master's candidate at MIT's Sloan School of Management. For further details, see Allan Will, "Deep Ocean Mining: A Strategic Business Analysis", May 1981, on file at Dewey Library, MIT. The work was completed before several relatively minor adjustments in cost estimates were made. These changes produced a change in total capital costs from $1,140 million to $1121 million, plus, in each case, pre-production costs of $172 million. Annual operating costs changed from $ 223 to $ 217 million. The next effect of these adjustments is to change the IRR from 9.21% to 9.76%. The first computer printout in Appendix 8 contains the latter cost estimates. The second printout contains the assumptions as they stood at the time cost analyses reported in this chapter were made.

4. Unless specifically noted, the analyses in this section were based on the timing assumptions represented in Figure 1-C, in chapter II. Differences between the assumptions in Figure II-1-C and 1-D were discussed in chapter II. The significance for financial analysis is that the cost of precommercial mining prospecting and exploration, estimated at $ 30 m.,would be spread over an additional six years to year 16 rather than ending in year 10 as was assumed in the analyses. When such a change is made, the "baseline" IROR changes from 9.21% to 9.01%. The assumption that the $ 30 m. total remains the same appears to be valid, particularly in light of the reduction in levels of industry activity since 1980. The first computer printout in Appendix 8 reflects Figure II 1-D, while the second reflects 1-C.

5. New York Times, "Law of the Sea Review Welcomed," p.D1, April 7, 1981.

APPENDICES

Appendix 1. NOTE ON RELATION BETWEEN MODEL'S COST ESTIMATES AND FINANCIAL ANALYSIS

The model of the project contains a cost estimation section and a financial analysis section. The cost estimation section divides the capital and operating costs into the following ten sectors:

Sector 1: Preparatory Costs
Sector 2: Mining
Sector 3: Marine Transport
Sector 4: Ore Discharge Terminal
Sector 5: On Shore Transportation
Sector 6: Processing
Sector 7: Waste Disposal
Sector 8: Marine Support
Sector 9: General Administrative
Sector 10: Continuing Preparation

Chapter 3 describes the manner in which the capital and operating cost estimates associated with these sectors, as developed in chapter 2 and related appendices, are taken into the financial analysis section. This appendix supplements that material, particularly by providing additional detail concerning preparatory costs.

Each of the ten sectors contains two programming arrays, called CAPCST and OPCST, respectively. Costs are allocated to these arrays depending upon their tax treatment. That is, costs are assigned to the CAPCST array if they are capitalized and to the OPCST array if they are expensed.

Capital costs for sectors 2-9 are always assigned to the CAPCST array and operating costs are always assigned to the OPCST array. Total capital cost for the project is calculated by the model as the sum of the CAPCST arrays for sectors 2-9. The sum of the OPCST arrays for sectors 2-9 comprises the total annual operating cost for the project.

For sectors 1 and 10, anomalies in the tax laws require further distinction of operating costs. Therefore, costs are allocated to the arrays, by subsector, as determined by these distinctions -- "capitalizable" costs to CAPCST and "expensable" costs to OPCST. The allocation mechanism is as illustrated in Table 1-1.

TABLE 1-1

ALLOCATION OF PREPARATORY COSTS TO CAPITAL AND EXPENSE ACCOUNTS

Subsector	When Capitalized	Allocated To	OR	When Expensed	Allocated To
Prospecting	Capitalized	CAPCST(1,1)		Expensed	OPCST (1,1)
Exploration	"	" (1,2)		"	(1,2)
R & D	"	" (1,3)		"	(1,3)
Project Feasibility	"	" (1,4)		"	(1,4)
Permitting	"	" (1,5)		"	(1,5)
Up Front G & A	"	" (1,6)		"	(1,6)
Bonus	"	" (1,7)		"	Bonus is always capitalized

Based on the user's input parameters, the model selects which costs, or fractions of costs, are expensed and which are capitalized. The model aggregates these costs and assigns the capitalized preparatory costs to sector 1 of the CAPCST array and the expensed preparatory costs to sector 1 of the OPCST array. The sum of the OPCST arrays for sectors 1 and 10 is handled as miscellaneous expenses.

Expensing is usually preferred where allowed by law. R & D, project feasibility, up front G & A and permitting are all handled in that manner.

According to present tax law, continuing preparations, (i.e., ongoing P & E,sector 10) are considered developmental and may therefore be expensed.

Appendix 2. MINING

The mining sector includes the mineship, the pipe string, the pumping system, the collector, and all support equipment and spares. The vessel has the configuration of an ore carrier with nodule storage capacity evaluated on the basis of the capacity and number of transport ships and the annual production rate. A moonpool is installed together with a derrick, cranes, a pipe rack capable of storing 18,000 ft. of 12" ID pipe with fairing, and associated equipment. A slurry transport system is installed to carry the nodules from the mineship to the transport ship including water jets in each hold, booster pumps and slurry pumps together with separate diesel engines.

The living quarters are designed to accommodate the crew and an additional 40 people required for the mining operation. A helicopter deck is installed.

The vessel is equipped with track-keeping thrusters capable of sustaining 45 mph wind, with waves described by sea state 5 fully developed seas and 1 knot current. The power system of the vessel consists of diesel engines driving ac generators, which supply the required power to either the main propellers in cruising mode, or the pumps and thrusters in mining mode.

The dredge system employs in-line two-phase flow pumps placed along the length of the pipe and driven by motors powered through electric cables by the main power system. A 12" inner diameter is assumed, while the thickness is tapered.

The collector is launched over the side of the ship and is equipped with sonars and underwater cameras for efficient steering.

A research vessel is included in the marine support sector to launch and retrieve acoustic transponders and perform oceanographic work (see Appendix 4).

1. Outline of Capital Cost Estimation

The mining sector is further divided into subsectors and subsubsectors which correspond to the functional working units of the whole mining operation. These subsectors, which are discussed in the next section, are:

2.1 Equipment and Supplies Handling
2.2 Nodule Pumping System
2.3 Dredge Pipeline
2.4 Collector Unit(s)
2.5 Ore Handling
2.6 Mineship (Main Structure)

Each of these is further divided into sub-subsectors which are described below (also see Figure 2-1). The sub-subsectors are divided into units for which costs can be derived. It is desirable to keep these units as large as possible, but sometimes the equipment arrangement mandates that small units be used. Thus, some of the cost items are individual pieces of equipment and other are entire sub-subsectors or subsectors.

The mining sector includes components which have never been implemented in full scale, nor tested for sufficient periods of time. Since this equipment is beyond the state of the art, basic sizing has been used to determine the dimensions and weight, and subsequently data from industry have been used to extrapolate the costs. This refers primarily to the dredge pipe and associated equipment, the pumps and motors, and the equipment required for at-sea transfer of nodules.

Primary references from industry were data from Flipse (Ref. 14), as well as the offshore industry (Ref. 15). Other references are listed at the end of the appendix. Once the size of each unit is known, its cost can be estimated from either cost estimating literature, or common industry data, or regression of these data. In some cases, costs are derived from unit material costs.

2. Capital Cost Estimates

This section describes each of the sub-subsectors briefly. The diagrams in Figure 2-1 shows how the sub-subsectors fit into the scheme of the whole mining operation. The total capital costs are given in the end of this section in Table 2-2.

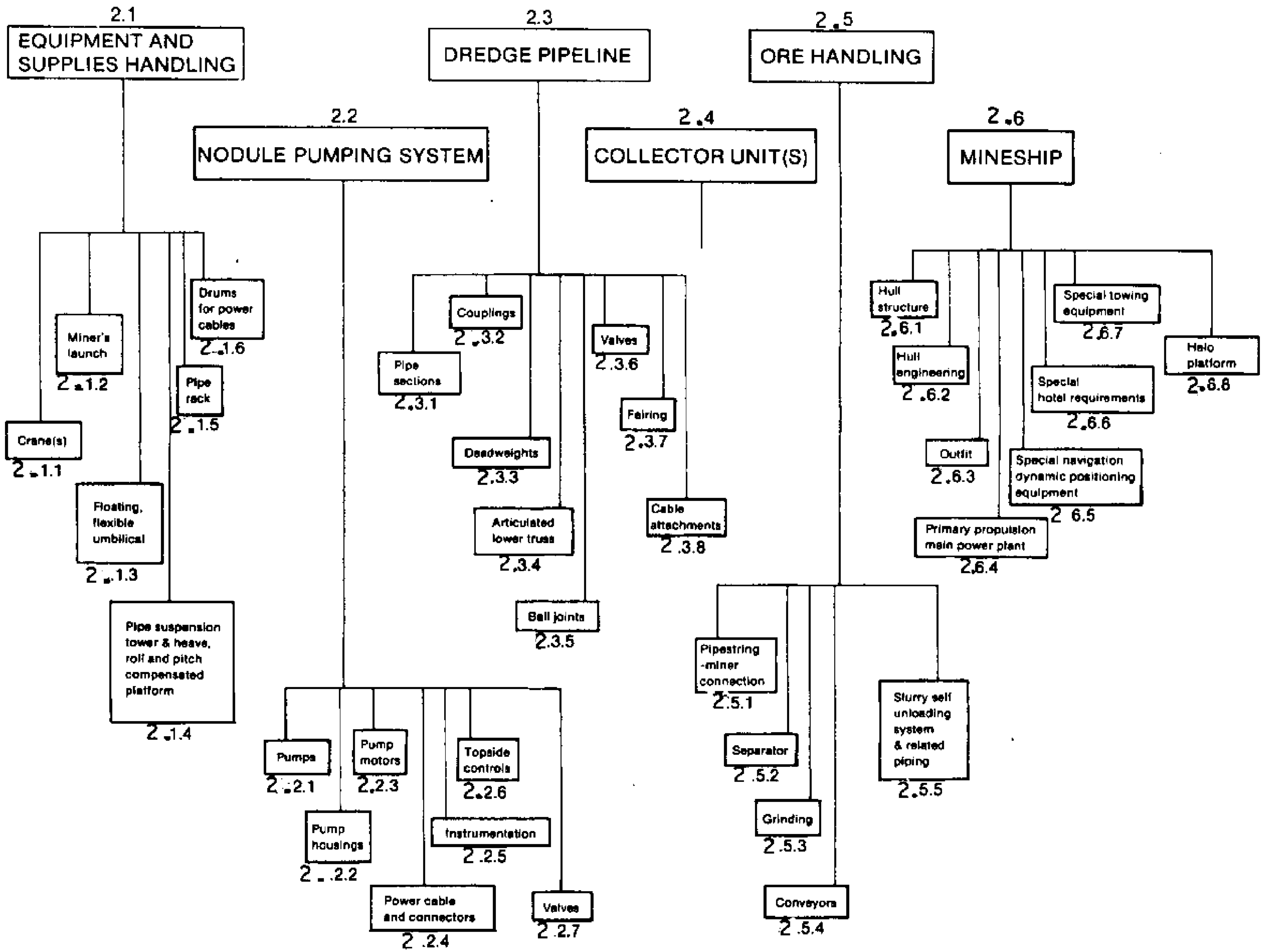


FIGURE 2-1 MINING SECTOR

2.1. Equipment and Supplies Handling

1. Crane(s)

Cranes are needed aboard the mining vessel for handling the collector, loading pipes and equipment, and handling the fuel, water, and nodule umbilicals, for the transport vessel. Two cranes are installed.

2. Launching of the Collector

Launched over the side with keel haul under the moonpool, a crane will be required with a 25-ton capacity and a special enclosure for working (Ref. 14).

3. Floating, Flexible Umbilicals

Floating, flexible umbilical hoses and pipes between the miner and transport vessels are necessary for the transfer of nodules, water, and fuel. Special equipment is provided for the connection between the mineship and the transport vessel.

4. Pipe Suspension Tower and Platform

A 150 ft. derrick is installed with a capacity of 2.5 10^6 lbs., together with gimball platform, heave compensator, pipe rack, and dome enclosure. Costing information is based on Refs. 14 and 15.

5. Pipe Rack

A pipe rack with skid-wag to the pipe suspension tower is included in the pipe suspension data (para. 2.1.d)(Refs 1 and 14).

6. Deck Mounted Drums for Power Cable

Deck mounted drums for the power cable for the lift-system pumps, collector cable and instrumentation cables are installed. Ref. 14 has been used for costing.

2.2. Nodule Pumping System

1. Pumps

Pumps used for the lift-system are specified according to the power required to pump the nodules from the seabed to the surface. Through calculations based on two-phase flow data (nodule-sea water), the power required to overcome headloss in the pipestring is found to be 9,500 HP. Assuming a pump efficiency of 50% only, since RPM will be kept very low to avoid excessive abrasion, we find the required electric power to be 18,900 HP. Four pumps will be used, 2,500 HP each. Ref. 15 has been used together with sizing procedure from Refs. 2, 5, 6, 7 and 11. The results are comparable with those of Flipse (Ref. 14).

2. Pump Housing

Cost included in 2.2.1.

3. Pump Motors

Cost included in 2.2.1.

4. Power Cable and Connectors

Power cable and connectors to provide power for the pumps and connection between the miner and the collector are provided. Refs. 2 and 14 have been used.

5. Instrumentation

Instrumentation for the pumping system is provided. Refs. 2, 7 and 14 have been used.

6. Topside Controls

A topside control room is required including a computer controls facility, TV screen, stress monitors, etc. Ref. 14 has been used.

7. Valves (Dump and Diffusion)

Cost included in 2.2.1.

2.3. Dredge Pipeline

1. Pipe Sections

Pipe sections are individual sections of the pipestring, each measuring 40 ft. in length, totalling 18,000 ft. For hydraulic lift, the inner diameter is constant at 12 in., and is the basis for weight calculations. The thickness of the pipe sections is varied to achieve a constant stress level. Overall weight including an additional 25% for the weights of joints and attachments = 2.0×10^6 lbs. (for a yield stress level of 120,000 psi). The price can be found using data from risers. A sizing as reported in Ref. 17 has been used and the cost estimated from Refs. 14 and 15 with some information drawn from Refs. 3, 5, 6, 11 and 16.

2. Couplings

Cost included in 2.3.1.

3. Deadweights

A bottom deadweight of 20 tons is used. Cost included in 2.3.5.

4. Cable Attachments

Cost included in 2.2.1.

5. Articulated Lower Hose

A bottom hose 1,200 ft. long by 12 in. internal diameter is used to connect the pipe to the collector. The cost includes buoyancy material, cables, and flanged joints.

6. Ball Joints

Ball joints or flexible pipe joint attachments are costed together in 2.3.1.

7. Valves (Dump and Relief)

Cost included in 2.2.1.

8. Fairing

No buoyancy materials are used for the main pipestring, but splitter plates are installed to avoid vortex shedding (costed together in 2.3.1.)

2.4. Collector Unit(s)

The collector is costed as a unit (Ref. 14). A spare is included on the mineship. It is equipped with underwater camera and sonar, an accumulator where a five minute nodule mass will be stored and from which the pipe will pump, so as to avoid over- and under-loading of the pipe depending on the abundance of nodules on the floor. The five minute interval is selected to reflect the time required to change the propulsion speed or to maneuver the collector. (Ref. 13).

2.5. Ore Handling

1. Pipestring-Miner Connection

Cost included in 2.3.1.

2. Separator (Water-Nodule Separation)

Cost included in 2.5.4.

3. Conveyors (For Transfer of Nodules to Holds)

Cost included in 2.5.4.

4. Slurry Self-Unloading System and Related Piping

A slurry self-unloading system for each hold is required aboard the miner. Initially, the slurry pumped through the pipe string is stored in five holds and the excess water decanted until a mixture of 90% in nodules by weight is achieved. When the transport ship arrives, the ore is mixed with water, using eight high pressure jets per hold until a uniform mixture of 60% by volume in nodules is achieved. Then the booster pumps drive the slurry to the main collection tank from where the main jumps drive it through a 10-inch pipe to the transport ship holds.

Each hold is equipped with valve actuated water jets. Slurry and booster pumps are used driven by separate diesel engines. The jets are used to slurrify the nodules and the pumps to transport the slurry. A description of the system can be found in Ref. 18. The results are comparable with those of Ref. 14.

2.6. Mineship

1. Hull Structure

By using a modified version of the design procedure for the ore carriers outlined in the transportation section, the dimensions and costs of the mining ship are obtained.

The modifications include:

--Increase in dimensions caused by the moonpool.

--Addition of space needed for the slurry pumps.

--Addition of space and weight for personnel.

--Addition of weight from the derrick, moonpool, pipe, pipe rack, and associated equipment.

--Addition of horsepower required to drive the main pumping and the thrusters.

The dimensions of the miner have been based on data from ore carriers (references from Appendix 3) using an augmented DWT to account for the additional weights.

The following dimensions are obtained for the base case:

TABLE 2-1. BASE CASE MINESHIP, DIMENSIONS AND COST

Dimensions

Length	=	732 Ft.
Beam	=	113 Ft.
Draft	=	44.5 Ft.
Depth	=	59 Ft.
C_b	=	0.85 Ft.

Steel Weight	=	14,700 Tons
Outfit Weight	=	1,600
Machinery Weight	=	1,200
Mining Equipment	=	12,000
DWT	=	56,000
Displacement (Moonpool Open)	=	85,500

Labor Cost	=	26.84 Million $
Overhead	=	17.89
Material	=	25.86
Profit	=	7.06

2. Hull Engineering

Hull engineering costs are included in 2.6.1.

3. Outfit

Cost included in 2.6.1.

4. Primary Propulsion and Main Power Plant

Total machinery weight = 1,200 tons and is costed in 2.6.1.

5. Special Navigation and Dynamic Positioning Equipment

A number of 2,500 HP thrusters are used. For the basic case, six thrusters are required (three in bow, three in stern). The thrusters are retractable, AC motor driven, controllable pitch propellers including duct, motor, propeller, and casing.

6. Special Hotel Requirements

Special hotel requirements are accounted for at an estimated $2.00 million.

7. Special Towing Equipment

Special towing equipment is required if the mineship must tow the transport ships during nodule transfer procedure. Such special towing arrangements are provided for the current base case.

8. Helicopter Platform

A helicopter platform is required to transfer of personnel and supplies.

Data from Ref. 14 have been used for 2.6.1 through 2.6.8, and the total results are comparable with those of the same reference (Flipse).

3. Operating Costs Estimates

For a summary of operating costs, see Table 2-3. The following operating costs are estimated:

3.1. Maintenance Cost

The maintenance cost is estimated as a percentage of the respective capital cost (Ref. 14).

	PERCENT
2.1 Equipment and Supplies Handling	5
2.2 Nodule Pumping System	50
2.3 Dredge Pipeline (Spare Not Included)	50
2.4 Collector Unit (Spare Not Included)	50
2.5 Ore Handling	5
2.6 Mineship	2

3.2. Crew Cost

The number of crew is determined, as with the transport ship, as a function of the ship size. The average salary is evaluated at $71,000/man per year. Two full crews of 40 people each are necessary for each mineship on a 30-days-on/30-days-off schedule.

3.3. Fuel Cost

The fuel and lubrication cost can be calculated directly. The power consumption is assumed to be as follows: (as percentage of installed power of specific equipment)

	At-Sea Mining	At-Sea Not Mining
Main Propulsion	83%	41%
Thrusters	25%	12.5%
Mining Equipment	100%	10%

The power consumption in port is assumed to be negligibly small.

The fuel consumption is 165^{gr}/ HP hr.

The lubrication oil consumption is 1^{gr}/ HP hr.

The cost of diesel 180 centistoke is taken $158/ ton and the cost of lubrication oil is taken as $950/ ton.

3.4. Insurance Cost

The insurance cost is estimated as 1.5% of total value of equipment plus $1,500 per crew member.

3.5. Layup Charges

The layup charges are assumed to be a fraction of the different operating costs of the mineship.

TABLE 2-2. TOTAL CAPITAL COSTS PER MINESHIP
(in millions of 1980 U.S. $)

		COST
2.1.	EQUIPMENT AND SUPPLIES HANDLING	
	1. Crane(s)	
	2. Miner's Launch	
	3. Floating, Flexible Umbilical	
	4. Pipe Suspension Tower and Platform	
	5. Pipe Deck	
	6. Deck Mounted Drums for Power Cable	
	TOTAL	17.05
2.2.	NODULE PUMPING SYSTEM	
	1. Pumps	
	2. Pump Housings	4.00
	3. Pump Motors	
	4. Power Cable and Connectors	6.40
	5. Instrumentation	2.00
	6. Topside Controls	
	7. Valves (Dump and Diffusion)	
	TOTAL	12.40
2.3.	DREDGE PIPELINE	
	1. Pipe Sections	
	2. Couplings	
	3. Deadweight	
	4. Cable Attachments	
	5. Articulated Lower Truss	
	6. Ball Joints	
	7. Valves (Dump and Relief)	
	8. Fairing	
	TOTAL	19.60
2.4.	COLLECTOR UNIT(S)	3.50
2.5.	ORE HANDLING	
	1. Pipestring-Miner Connection	
	2. Separator	
	3. Grinding	
	4. Conveyors	
	5. Slurry Self-Unloading System and Related Piping	
	TOTAL	10.20
2.6.	MINESHIP (MAIN SECTION)	
	1. Hull Structure 2. Hull Engineering 3. Outfit 4. Primary Propulsion and Main Power Plant	77.65
	5. Special Navigation and Dynamic Positioning Equipment	9.40
	6. Special Hotel Requirements	2.00
	7. Special Towing Equipment	0.90
	8. Helicopter Platform	0.40
	TOTAL	90.37
	TOTAL FIXED CAPITAL INVESTMENT	$153.12
TOTAL CAPITAL COST FOR TWO MINESHIPS		$306.24

TABLE 2-3. OPERATING COST SUMMARY
(in millions of 1980 U.S. $)

Maintenance		
2.1.	Equipment and Supplies Handling	0.85
2.2.	Nodule Pumping System	6.20
2.3.	Dredge Pipeline	5.05
2.4.	Collector Unit	0.95
2.5.	Ore Handling	0.51
2.6.	Mineship	1.81
		$15.37
Crew Cost		9.94
Fuel Cost		4.68
Insurance		2.54
Lay-up		0.26
	TOTAL OPERATING COST	$32.79
TOTAL OPERATING COST FOR TWO MINESHIPS		$65.58

75% Maintenance Cost

10% Annual Crew Cost

25% Insurance Cost

Data from Ref. 14 were used and the results were comparable with those of the same reference (Flipse).

4. Alternative Case

The storage capacity of the mining vessel depends upon the number and size of transport ships. When the distance from port to minesite changes to 2,500 nautical miles, four transport ships of 62,000 DWT are needed (see Marine Transport Appendix 3). The required storage capacity for the mineship is then increased to 75,000 DWT (margin: 20%).

The capital and operating cost summaries for the alternative case are given in Tables 2-4 and 2-5.

TABLE 2-4. CAPITAL COST SUMMARY ALTERNATIVE CASE
(in millions of 1980 U.S. $)

2.1.	Equipment and Supplies Handling	17.05
2.2.	Nodule Pumping System	12.40
2.3.	Dredge Pipeline	19.60
2.4.	Collector Unit	3.50
2.5.	Ore Handling	10.20
2.6.	Mineship	98.56
	TOTAL FIXED CAPITAL INVESTMENT (for one mineship)	161.31
TOTAL CAPITAL COST FOR TWO MINESHIPS		$322.62

TABLE 2-5. OPERATING COST SUMMARY ALTERNATIVE CASE
(in millions of 1980 U.S. $)

Maintenance	15.53
Crew Cost	10.08
Fuel Cost	4.77
Insurance	2.58
Lay Up	0.27
TOTAL OPERATING COST (for one mineship)	33.23
TOTAL OPERATING COST FOR TWO MINESHIPS	$66.46

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Appendix 3. MARINE TRANSPORT

The ships that transport the nodules are similar to ore carriers or bulk carriers given the specific gravity of the nodules, which is close to two. A large number of such ships have been constructed and an abundance of data exists. For this reason, in the present study data from existing ships are used in a generic form to allow the user to vary some parameters and to update the costs easily. In parallel, data from the industry have been used to verify all the costs derived.

The capital and annual operating costs presented in this appendix are for a transportation scheme that handles a total of 4.5 million tons of wet nodules per year. As mentioned, the transport vessels are similar to ore carriers due to the specific gravity of the decanted slurry. Ore carriers are deadweight limited vessels and, in accordance with the scenario they are limited in size by the draft restriction of the port. Further assumptions are as follows:

- --The number of mineships used in the marine transportation program is fixed and equal to two.
- --Each mineship is serviced by an equal number of transport ships.
- --Those transport ships are assumed to be equal in size.
- --The transport ships are traveling between one mineship and the port terminal. A roundtrip which involves both mineships is not considered.

The marine transport sector includes all systems required to carry the nodules from the mineship to the port. Special preparations and facilities necessary to accommodate the transport vessels at port are included in the ore discharge port sector, Appendix 4.

1. Outline of Capital Cost Estimations

The transport ships are initially divided into subsectors and sub-subsectors which correspond to the functional working units of the vessel. The subsectors, discussed in section 3. Capital Costs, are:

3.1 Ship Hull
3.2 Slurry Transfer Equipment
3.3 Fuel, Water, and Supplies Storage and Transfer Equipment
3.4 Special Equipment Necessary for At-Sea Coupling with Miner
3.5 At-Sea Disposal Equipment

The subsectors are divided into units for which costs can be derived. It is desirable to keep these units as large as possible, but sometimes the equipment arrangement mandates that small units be used.

The ship price is for United States ship construction. The price is estimated by direct calculation of the labor and material costs, and will therefore be slightly different than the actual market price. The ship size is estimated using methods suggested by D.G.M. Watson (Ref. 1).

The labor and material costs are estimated from G. Carreyette (Ref. 4) modified for U.S. construction. The methodology traces back to Benford (Ref. 11). The cost of labor is taken as $15 per manhour. The overhead costs are taken as two-thirds of the labor costs.

A profit margin of 10% is used, which includes actual profits, insurance costs, and owner expenses. Cost estimation data were used from Flipse (Ref. 9) and Andrews (Refs. 3 and 6) in addition to the references mentioned above. The overall results are comparable with those of Refs. 3 and 6.

2. Number of Ships

The distance between port and mineships for the base case is 1,750 miles. Two identical fleets of transport vessels serve the two mineships separately. The number of ships satisfies the draft restriction at the port, and the vessels are loaded at least 80% for their capacity but not more than 90%. For the base case, 300 operating days are assumed, a port draft of 40 feet, and loading time of 24 hours. The port draft is rather restrictive for the sites considered so the sizing of vessels allows up to 10% changes for draft limited operation. For the base case four transport ships are required with a DWT of 44,700 tons. The nodule storage capacity of the mining vessel (See Appendix 2, Mining) is selected as the minimal capacity capable of handling the given transport vessels plus a 25% margin. The mining calculations therefore follow after the transportation calculations.

The average trip duration between mine site and port equals the time required to travel both ways, plus the time to load and unload the cargo, plus port delays. An estimated 20 hours are required for loading the transport ship so the total delay time is estimated at 48 hours per round trip.

If N denotes the number of transport ships, DWT the deadweight, U the ship speed in knots, D_s the distance between site and port in miles, and Q^S the annual nodule tonnage in net tons, then the number of ships is the smallest integer equal to:

$$N = \frac{Q \quad \frac{2 * D_s}{V} + 48}{0.9 * DWT * 300 * 24 \text{ Hr/Day}}$$

3. Capital Costs

The cost estimation procedure is provided by subsectors according to the division indicated in figure 3-1. For capital cost summary, see Table 3-2.

3.1. Ship Hull

1. Hull Structure

The nodules have a specific gravity of two; thus an ore carrier or bulk carrier configuration must be used. Dedicated tanks to transport fuels and water to the mineship are up to 10% of the DWT capacity. Additional pumps and piping

FIGURE 3-1.
MARINE TRANSPORT, SECTOR 3

3.1. SHIP(S) HULL (MAIN TRANSPORTS, GEARLESS)
- 3.1.1. Hull Sturcture (includes materials, labor, overhead, and miscellaneous items)
- 3.1.2. Outfitting (includes materials, labor, overhead, and miscellaneous items)
- 3.1.3. Hull Engineering (includes materials, labor, overhead, and miscellaneous items)
- 3.1.4. Propulsion Machinery (includes materials, labor, overhead, and miscellaneous items)

3.2. SLURRY LOADS & DISCHARGE EQUIPMENT
- 3.2.1. Deck Piping and Manifold System (for receiving nodule slurry from mineship)
- 3.2.2. Dewatering Pumps and Piping for Each Hold
- 3.2.3. Reslurrying Equipment

3.3. FUEL, WATER, AND SUPPLIES STORAGE AND TRANSFER EQUIPMENT
- 3.3.1. Miner Fuel Dedicated Storage Tank(s)
- 3.3.2. Miner Fuel Pumps and Piping
- 3.3.3. Miner Fresh Water Dedicated Storage Tank(s)
- 3.3.4. Miner Fresh Water Pumps and Piping
- 3.3.5. Deck Crane for Handling Slurry, Fuel, and Water Umbilical from Mineship

3.4. SPECIAL EQUIPMENT NECESSARY FOR SEA COUPLING WITH MINER (To be developed; includes navigation and control equipment for transport-miner interface)

3.5. AT-SEA DISPOSAL EQUIPMENT

are needed for slurry handling, dewatering and decanting, and sea water handling.

The sizing procedure described by Watson (Ref. 1) is used to obtain the principal dimensions of the vessel and the various weights and manhours required, also satisfying the considerations on the number of ships. A 10% change is allowed for restricted draft operation (Ref. 12). Using material prices, labor costs, and overheads applicable to U.S. construction, the cost of the hull is obtained as outlined by Carreyette (Ref. 2) and Benford (Ref. 11). For base case see Table 3-1.

2. Outfitting

Cost estimation as outlined in Refs. 1 and 2 and described in 3.1.1.

3. Hull Engineering

Cost estimates as outlined in Refs. 1 and 2 and described in 3.1.1.

4. Propulsion Machinery

The Series 60 are used to obtain estimates of the horsepower required. For the base case the engine's maximum continuous rating is 16,850 HP. Cost estimation follows Refs. 1 and 2. A direct drive diesel engine using diesel 180 centistoke is assumed.

3.2. Slurry Loading System

1. Deck Piping and Manifold System

2. Dewatering Pumps and Piping for Each Hold

The nodules are loaded on the transport vessel in slurry form without prior grinding. The nodules are first dewatered from the bottom of the hold and subsequently decanted to about 90% solids. When in port the load is fluidized by using water jets as described in Ref. 7 and subsequently pumped to the port terminal.

A pumping capacity of 5,000 tons of slurry per hour for 100,000 DWT ship is reported and linear decrease of this

TABLE 3-1.

TRANSPORT SHIP DIMENSIONS(BASE CASE)

Length (BP)	=	631	Ft.
Beam	=	97	Ft.
Draft	=	38.3	Ft.
C_b	=	0.82	Ft.
Engine Horsepower	=	16850	HP
V_s	=	15	Knots
Δ	=	55000	Tons
DWT	=	44700	Tons
Lightship	=	10300	Tons

TABLE 3-2.

MARINE TRANSPORT CAPITAL COST SUMMARY

(per 44,700 DWT transportship)

		TOTAL CAPITAL COST ($ million)
3.1.	Ship, Nodule Transport	
	3.1.1. Hull Structure	
	Materials	3.80
	Labor	8.40
	Overhead	5.60
	3.1.2. Outfitting	
	Materials	4.42
	Labor	4.94
	Overhead	3.29
	3.1.3. Hull Engineering (included in 3.1.a.)	
	3.1.4. Propulsion Machinery	
	Materials	6.37
	Labor	3.96
	Overhead	2.64
	Profit	4.34
3.2.	Slurry Load System	1.16
3.3.	Fuel, Water, and Supplies Storage and Transfer Equipment	0.30
3.4.	Special Equipment Necessary for At-Sea Coupling with Miner	1.00
TOTAL FIXED CAPITAL INVESTMENT		$50.22
TOTAL CAPITAL COST OF FOUR TRANSPORT SHIPS		$200.88

capacity is assumed for smaller vessels (Refs. 6 and 7).

The cost of the slurry loading system is estimated as a linear function of deadweight. The following equation was obtained using existing data (Ref. 7) (Updated 1980 data in U.S. dollars.)

Cost = 556,700 + 13.3 * DWT

3.3. Fuel, Water, and Supplies Storage and Transfer Equipment

1. Miner Fuel Dedicated Storage Tanks
2. Miner Fuel Pumps and Piping
3. Miner Fresh Water Dedicated Storage Tanks
4. Miner Fresh Water Pumps and Piping
5. Deck Crane

These costs of 3.3.2, 3.3.4, and 3.3.5 are added to the ship cost. Data from Andrews (Refs. 3 and 6) were used.

3.4. Special Equipment for At-Sea Coupling with the Miner

A major part of the navigation and control equipment necessary for at-sea coupling between the miner and the transport ship is included in the mining sector. The at-sea transfer of cargo requires further investigation and the costs are tentative. Data from Andrews (Ref. 3), Flipse (Ref. 9), and Halkyard (Ref. 10) were used.

3.5. At-Sea Disposal Equipment

This option is not considered in the base case.

4. Annual Operating Costs

A summary of annual operating costs is given in Table 3-3.

TABLE 3-3

ANNUAL OPERATING COST SUMMARY

(Per 44,700 DWT Transportship)

(in millions of 1980 U.S. $)

Crew Cost	1.94
Maintenance Cost	0.50
Insurance	0.58
Fuel Cost	2.24
Port Charges	0.13
Lay-up Charges	0.13
Miscellaneous	0.00
TOTAL ANNUAL CHARGES	5.52
TOTAL OPERATING COST FOR FOUR TRANSPORT SHIPS	$22.08

4.1. Crew Salaries

The total number of crew is determined as a function of the DWT of the transport ship:

DWT	Number of crew
30,000	28
40,000	29
55,000	30
70,000	31
85,000	32

Annual salary per crew member = 60,260 + 0.15 x DWT.

4.2. Maintenance

The maintenance cost of the transport ship with a slow speed diesel is assumed to be a function of maximum continuous engine rating and DWT (Ref. 3). The maintenance cost of the slurry system is assumed to be 10% of the capital cost of the slurry system.

4.3. Insurance

The insurance cost is a function of the DWT and the capital cost of the ship (Ref. 3).

4.4. Fuel Cost

The fuel and lubrication cost for a slow speed diesel engine can be calculated as:

$$\text{Fuel price per day} = \text{sfc} \times \text{MCR} \times \text{cbc} \times \frac{24}{1{,}000{,}000 \times 1.2}$$

sfc = Specific fuel (lubrication oil) consumption per day (gr/HPh)

MCR = Maximum continuous engine rating

cbc = Price per metric ton

As specific fuel consumption estimates, the following were selected (Ref. 4):

Specific fuel consumption main engine	= 155	gr/HPh
Specific lubrication oil consumption	= 0.93	"
Specific fuel consumption auxiliaries	= 165	"
Specific oil consumption auxiliaries	= 1	"

The power used by the auxiliaries is assumed to be 4% of the maximum continuous rating of the main engine. The assumption is made that in port the auxiliaries are operating continuously and that for loading at sea 40% of the main power and the auxiliaries are operating.

4.5. Port Charges

Port charges are calculated from linear regression of available data.

Port charges first day = 1650 + 0.078 DWT$

Port charges second day = 133 + 0.0267 DWT$

4.6. Lay-up Charges

Lay-up charges are taken as a percentage of the normal operating charges (Ref. 5).

$$\text{Lay-up charges} = \frac{365 \text{ Operating Days}}{365} \times (0.1 \text{ Labor} + 0.75 \text{ Maintenance} + 0.25 \text{ Insurance})$$

5. Alternatives to the Base Case

The distance between port and mineship may vary between 1,700 and 3,500 miles depending on the site selected. A different transportation scheme is to be selected for each case following the same procedure as outlined for the base case. Also the impact of the port restriction can be directly assessed.

The program written to evaluate the cost of the transportation vessels can handle changes in the basic inputs of distance between port and minesite, port draft, the number of operating days per year, and port time.

It should be noted that the storage capacity of the mineship must be selected on the basis of the transport vessel deadweight, so that the impact of changes in the inputs above on the mining sector costs is substantial.

See Table 3-4.

TABLE 3.4

SUMMARY OF RESULTS

Draft Restriction (Feet)	35	40	50
Distance (N. Miles)	1750	1750	1750
Number Ships	4	4	2
DWT	44700	44700	89300
Total Capital Cost (M$)	205.2	200.9	139.2
Total Annual Cost (M$)	22.6	22.0	15.4

Draft Restriction (Feet)	35	40	50
Distance	2500	2500	2500
Number Ships	6	4	2
DWT	41400	62000	124000
Total Capital Cost (M$)	292.7	237.8	169
Total Annual Cost (M$)	32.9	26.1	18.9

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Appendix 4. ORE DISCHARGE PORT
MARINE SUPPORT
ON-SHORE TRANSPORTATION

This appendix includes all cost calculations for the following sectors:

Part I:	Ore Discharge Port	(Sector 4)
Part II:	Marine Support	(Sector 8)
Part III:	On-Shore Transportation Slurry Pipelines	(Sector 5)

Part I. ORE DISCHARGE PORT

The ore discharge terminal provides for the discharging of manganese nodules from the ore carriers, temporary storage for the nodules, and preparation of the nodules for slurry pipelining to the processing plant.

1. Methodology of Cost Calculation

It seems likely that the mining consortium would want to lease a marine terminal from the port authority for the expected length of its operation or 60 years, whichever is less. In time, after the mining consortium has started using the facilities of the dedicated marine terminal, it may then consider any helpful conversions or transformations of the facilities to suit its own purpose efficiently. This is done only with approval of the port authority.

2. Cost Estimations

The further subdivision of subsectors into their sub-subsector components will be illustrated below, with capital and operating costs for all components enumerated.

As explained above, the ore discharge marine terminal serves as the base for off-loading the manganese nodules from the transport vessels and preparing them for pumping to the processing plant. In addition, at this facility the diesel fuel for the mineships is loaded into the ore carriers for the return trip to the mineships.

For this analysis, the terminal is assumed to be located in a developed deepwater port on the West Coast of the United States. This port must have a minimum channel depth of 40 feet in salt water at low tide. The ore discharge terminal must be capable of accommodating ore transport vessels up to 45,000 DWT capacity as defined in Marine Transport, Sector 3.

3. Sub-subsector Breakdown and Capital Costs

The required equipment and facilities for the ore discharge port sector are grouped into the following subsectors:

3.1 Terminal Land
3.2 Terminal Site Development
3.3 Terminal Buildings
3.4 Pier(s) and Pier Equipment
3.5 Dredging
3.6 Fuel Pipeline
3.7 Slurry Discharge Units and Related Piping
3.8 Nodule Storage Basin(s)
3.9 Water Recycling Tankage and Return Water Piping

3.1. Terminal Land

The ore discharge marine terminal will require 15 acres of land in a developed deepwater port. The land in most developed deepwater ports with access to a commercial channel is, in general, owned by the state, and therefore cannot be purchased outright. Instead, the interested party must lease the land from the port authority which manages the port facility. The leased land (and facilities) can be in varying stages of development, from bare, totally undeveloped land, to a facility with fully constructed pier(s), buildings, and general terminal services.

For this analysis, it will be assumed that the consortia involved in mining will elect to lease totally undeveloped land. This choice allows the ore discharge marine terminal to be tailored to meet the specific requirements of a nodules receiving and handling terminal. The land will be leased at a rate of $.50 per square foot per year. Thus, annual lease charges for the terminal land will be $300,000. (Ref. 1)

3.2. Terminal Site Development

The site development sub-subsector will include provisions for land preparation, site services and utilities, and yard items. Land preparation will include surveying, grading, and leveling of the terminal land, as necessary. The site services and utilities will include fresh water service lines, electrical power, a sewerage system, telephone service, and sotrm drainage facilities. Fencing, lighting, parking, and internal roads will comprise the yard items.

The total direct capital cost for this subsector is $850,000. When indirect capital costs, contingency fees, and contractor fees are added (calculated as 6% of the above) the total capital expenditure for this sub-subsector is $872,000.

3.3. Terminal Buildings

The capital cost for the buildings includes the buildings for offices, maintenance and repair, storage, and pumps for the slurry pipeline.

The total direct capital cost for the buildings sub-subsector will be $2,200,000. When indirect capital cost, contingency fees, and contractor fees are added (calculated as 10% of the above), the total capital expenditure for the sub-subsector will be $2,320,000.

3.4. Pier(s) and Pier Equipment

For this analysis, it has been determined that the pier must be able to handle vessels up to 45,000 DWT. The pier has provisions for crane rails on the deck, which are able to support the portable slurry discharge units. The necessary cranes to handle this unit also are installed.

The direct capital cost of the pier is $5,070,000 and the cost of the cranes is $5,080,000. An 8% increase is added to these costs for indirect capital costs, contingency fees, and contractor fees.

3.5. Dredging

In order to accommodate the transport vessel at the pier, the water depth next to the piers must be at least equal to the draft of the vessel plus a safety margin. In order to achieve this depth, dredging of the sea adjacent to the piers must be undertaken.

The cost per cubic meter for the dredging and disposal activities is $13. Thus, the total direct capital cost for this operation is $1,370,000. With the addition of indirect capital costs, contingency fees, and contractor fees (8% of above), the total capital cost of this dredging sub-subsector becomes $1,480,000.

3.6. Fuel Pipeline

The ore discharge marine terminal is the point at which diesel fuel for both the transport vessels and the mineships are loaded aboard the tranport vessel. Therefore, a fuel pipeline which connects with the local suppliers pipeline must be constructed. The direct capital cost for such a pipeline is $100,000. With the addition of indirect capital costs, contingency fees, and contractor fees (calculated as 8% of above), the total capital cost for this sub-subsector will be $108,000.

3.7. Slurry Discharge Units and Piping

The nodules are discharged from the transport vessels using portable slurry discharge units. These units are suspended in the holds of the transport vessel by dock-side cranes, with one discharge unit per hold. Using high pressure water, these discharge units re-slurry the nodules and then pump them from the vessel's hold, through a dock-side manifold system to the ore terminal nodule storage pond(s). In addition to the pipeline for transferring the nodules to the storage pond(s), there is also a need for a pipeline between the recycle water storage tank and the slurry discharge units.

This results in a direct capital cost of $5,170,000. When the indirect capital costs, contingency fees, and contractor fees (calculated as 12% of above) are added, the total capital cost for the sub-subsector will be $5,730,000.

3.8. Nodule Storage Basins

Nodule storage basins capable of handling two ship loads of nodules are required at the ore discharge marine terminal. These basins are constructed using soil embankments. Since the nodules are carried in a salt water medium, the bottom of the basins are lined with an impermeable synthetic liner, so as to prevent salt water intrusion into the ground water. In addition to the nodule storage basins, a reclaimer for recovering nodules from the basins and feeding them to the port-to-process plant slurry pipeline is required.

The nodule storage basins and the reclaimer cost is \$1,470,000. With the addition of indirect capital costs, contingency fees and contractor fees (calculated as 12% of above), the total capital cost for this sector is \$1,650,000.

3.9. Water Recycling Tankage and Return Water Piping

The slurry discharge units utilize a closed loop water system, thus preventing contaminated water from entering the local environment. Along with these tanks is a pipeline for transferring the excess transport water form the nodule basins to the water recycling tanks. The recycling tanks and the pipeline cost \$670,000. When the indirect capital costs, the contingency fees, and contractor fees are added, the total capital expenditure for this sub-subsector is \$750,000.

4. Operating Costs

The operating costs for the entire ore discharge marine terminal subsector can be grouped into categories as listed below:

4.1 Maintenance and Repair (M&R)
4.2 Labor
4.3 Utilities
4.4 Insurance
4.5 Taxes
4.6 Lease Fees
4.7 Miscellaneous

4.1. Maintenance and Repairs

The M&R costs for the ore discharge marine terminal subsector includes both labor and material costs required for maintaining the facilities in this subsector. This M&R cost is obtained by summing the M&R costs for the individual sub-subsectors. Each sub-subsector's M&R cost is, in turn, calculated on some percent of the sub-subsector total capital cost. A listing of M&R can be seen in table 4I-1. The total annual maintenance

TABLE 4I-1.

ANNUAL MAINTENANCE AND REPAIR COSTS

(Calculated as a percentage of the capital cost)

Site Development	(C 2%)	$ 17,000
Buildings	(C 2%)	26,000
Pier	(C 2%)	101,000
Cranes	(C 8%)	406,000
Dredging	(C 10%)	140,000
Fuel Pipeline	(C 1%)	1,000
Slurry Discharge Units	(C 10%)	517,000
Nodule Storage Basin	(C 1%)	15,000
Dirty Salt Water Tanks	(C 1%)	7,000
		$1,230,000

and repair cost for the entire subsector is $1,230,000.

4.2. Labor

The labor force in this subsector is divided into two groups, the permanent personnel and the temporary, or transient, personnel. The permanent personnel include the administrative staff, the operating team, and the M&R group. However, the cost of the M&R groups is included in the M&R operating cost cited above and need not be included in this operating cost category. The temporary personnel are the longshoremen, who must be hired on a shift basis for discharging the ore transport vessel.

The annual permanent personnel payroll, including overhead charges, will be $100,000 while the temporary personnel payroll will amount to $850,000 per year. Thus, the total annual labor costs for the ore discharge marine terminal subsector is $950,000.

4.3. Utilities

The utilities required for ore discharge terminal include electrical power and fresh water service. The terminal requires a total of 3,800,000 kilowatt-hours of electricity per year. General services requires 650,000 kilowatt-hours while the remaining 3,150,000 kilowatt-hours are consumed pumping fuel and water onto the transport vessels and discharging the nodules from the ore vessels. The power for the port-to-process plant pipeline is delivered to the pump house, at this terminal, but its cost is charged to the onshore transportation sector (Appendix 4, Part II). The total consumption of fresh water per year by the facility is 50M gallons. Using a electrical power cost of $.06 per kilowatt-hour and a fresh water rate of $.55 per 1,000 gallons, the total yearly power and water charges are $228,000 and $23,000 respectively. Thus the yearly utilities operating cost is $251,000.

4.4. Insurance

The insurance charges for the ore discharge marine terminal are estimated as a fraction of the total capital cost of the subsector. For this analysis, these charges are assumed to be 1% of the total capital cost. Thus the total annual insurance bill is $230,000.

4.5. Taxes

The state and local taxes on the ore discharge marine terminal are estimated as a fraction of the total capital cost of the subsector. For this analysis, these charges are assumed to be 1% of the capital cost. This gives a total annual state and local tax of $230,000.

4.6. Lease Fee(s)

The lease fee(s) for the ore discharge marine terminal is the annual charge for leasing the land upon which the terminal facility is constructed. This fee was discussed in section 3.1, where its cost was given as $300,000 per year.

4.7. Miscellaneous Items

For this analysis, there are no specific costs allocated under this operating group. However, it has been added to account for future, unforeseen cost items and for any additional operating costs associated with sensitivity analysis.

5. Summary

There follows, in tabular form, a summary of all the capital and operating charges applicable to the ore discharge marine terminal. In addition, the depreciation life of each capital cost sub-subsector is listed. The total capital and operating costs for the ore discharge marine terminal are $22,900,000 and $3,190,000 respectively (see Table 4I-2).

TABLE 4I-2.

ORE DISCHARGE TERMINAL CAPITAL AND OPERATING COSTS

(in millions of U.S. $)

ITEM	
Terminal Land	0.00
Site Development	0.87
Buildings	1.32
Piers	10.36
Dredging	1.48
Fuel Pipeline	0.11
Slurry Discharge Units and Piping	5.73
Nodule Storage Basins	1.65
Water Recycling Tankage	0.75
TOTAL	$22.87

ITEM	
M&R	1.23
Labor	0.95
Utilities	0.25
Insurance	0.23
Tax	0.23
Leases	0.30
TOTAL	$ 3.19

REFERENCES

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Appendix 4.

Part II. MARINE SUPPORT, SECTOR 8

1. Research Vessel (Fixed Cost)
2. Supply Vessel (Treated as a Fixed Item)
3. Support Vessel Marine Terminal
    - 3.1 Sub-subsector Breakdown and Capital Costs
        - 3.1.1. Terminal Land
        - 3.1.2. Site Development
        - 3.1.3. Terminal Buildings
        - 3.1.4. Pier(s) and Pier Equipment
        - 3.1.5. Dredging
        - 3.1.6. Fuel Pipeline
    - 3.2 Operating Costs
        - 3.2.1. Labor
        - 3.2.2. Utilities
        - 3.2.3. Lease Fees
    - 3.3 Summary
4. Crew Training
5. Marine Support Cost Summary

Table 4II-1. Support Vessel Marine Terminal Operating Costs

Table 4II-2. Marine Support Cost Summary (Base Case)

References

Part II. MARINE SUPPORT, SECTOR 8

1. Research Vessel (fixed cost)

A bottom survey and research vessel is required, capable of prolonged operations in deep water. It should be fitted with anti-rolling mechanisms and thrusters for dynamic positioning. The cost of the base ship is estimated at 4.5 million U.S. $ for a 200 ft. vessel (Refs. 1 and 4) capable of operating in the Pacific (Ref. 4).

The vessel is chartered at an annual cost of 11%, of its capital cost, i.e., $\$0.50*10^6$. The operating cost includes in addition fuel, supplies, equipment, and salaries estimated at $\$3.0*10^6$ annually (Ref. 4). Cost for crew training is provided for at $\$0.2*10^6$.

2. Supply Vessel (treated as a fixed item)

A relatively large vessel is required to carry personnel, technicians, and management aboard the mineship and the research vessel. The logistic support is located in Hawaii, 1,000 miles from the minesite. Ref. 5 suggests, from experience in the North Sea, a vessel of 170 ft. with a crew of eight and a speed of 20 knots requiring 2,000 HP at an estimated cost of 1.8 million U.S. $ (costed as in Ref. 6) and an annual operating cost of $8*10^5$ annually (Refs. 1 and 4).

The vessel is equipped with thrusters for the at-sea transfer of small equipment and personnel. It is capable of carrying up to 40 people and 20 tons of supply 50 times annually. It is fitted with a helicopter deck, while a helicopter will be leased.

3. Support Vessel Marine Terminal

As explained earlier, the support vessel marine terminal serves as the home base for both the mineship support vessel and for the P&E research vessel. This facility also accommodates the mineship logistics support office and warehouse and the P&E laboratories.

The terminal is located in an existing port facility which provides easy access to the minesite; thus either a Hawaiian or a southern California port might be chosen. Depth in the port channel should be about 25 feet in salt water at low tide. The depth is sufficient to accommodate the P&E vessel and the mineship support vessel. In addition, this port facility should be in an area which provides pleasant living conditions for mineship and P&E personnel.

Procurement of the support vessel marine terminal involves a leasing arrangement, wherein few or no additional capital expenditures on the part of the consortium are necessary. The feasibility of this type of leasing arrangement is due to the conventional configuration of this terminal, which requires standard, readily available terminal facilities and equipment.

3.1. Sub-Subsector Breakdown and Capital Costs

As outlined above, all facilities and equipment for the support vessel marine terminal are leased, thus precluding the need for any capital expenditures for this subsector. A breakdown of these facilities and equipment into sub-subsectors is as follows:

3.1.1. Terminal Land
3.1.2. Site Development
3.1.3. Terminal Buildings
3.1.4. Pier(s) and Pier Equipment
3.1.5. Dredging
3.1.6. Fuel Pipeline

1. & 2. Terminal Land and Site Development

The support vessel marine terminal requires 2 acres of land, fully developed with all utilities and yard items intact, as described for the ore discharge marine terminal. The land, all site development, and site services are leased at a rate of $0.50 per square foot, per year. This gives a yearly lease fee of $44,000 for the developed land.

3. Terminal Buildings

The support vessel marine terminal requires about 10,000 square feet of building space. Two thousand square feet of this area will be dedicated to offices, 8,000 square feet to the mineship logistics support warehouse and shops.

The office space costs $24 per square foot per year while the mineship logistics support warehouse and shops and the M&R shop(s) cost $6 per square foot per year. The cost of leasing the P&E laboratories is not priced here, but rather is included as part of the P&E expenditures. The total building lease fees attributable to this subsector are thus given as $96,000 per year. (Refs. 1 and 7)

4. Pier(s) and Pier Equipment

Berthing of the P&E research vessel and the mineship supply vessel requires 200 feet of pier space to be leased by the consortium. This pier has provisions for mobile cranes for handling supplies and equipment and for servicing the two vessels. The leasing cost for the pier facilities is $10 per foot per year, thus resulting in a total yearly cost of $24,000.

5. Dredging and Fuel Pipeline

The terminal facility leased is assumed to have a berth deep enough to accommodate the P&E and supply vessels; thus no additional initial dredging is required. Periodic dredging for depth maintenance is assumed to be undertaken by the owner of the facility with the cost of this activity being reflected in the lease fees.

A pipeline for fueling the P&E and supply vessels is required. This pipeline is also considered as part of the leasing package and therefore is reflected in the overall lease fees.

3.2. Operating Costs

The operating costs for the entire marine support terminal subsector can be grouped into the categories listed below:

1. Labor
2. Utilities
3. Lease Fees

From the above list it can be noted that there are no provisions for maintenance and repair (M&R), insurance, or tax expenditures for the support vessel marine terminal. The absence of these costs is because they are incurred by the lessor and not the lessee. However, as is common business practice, these costs are reflected in the annual lease charges paid by the lessee.

1. Labor

The labor force for the support vessel marine terminal includes the administrative and operating personnel responsible for the mineship logistics support operation and the running of the terminal facility. A staff of 6 people with a combined annual cost of $210,000, including overhead charges, is required. It should also be noted that personnel for the P&E laboratories are not accounted for in these costs, but are instead recognized in the P&E sector costs.

2. Utilities

The utilities required for the support vessel marine terminal include electrical power and fresh water. Thus the yearly utilities operating cost for the support vessel marine terminal are $10,000.

3. Lease Fees

The annual lease fees for the support vessel marine terminal include those for the land, buildings, and berthing facilities, as enumerated above. The sum of these annual charges is estimated to be $164,000, and constitutes the total annual lease payments for the entire support vessel marine terminal.

3.3. Summary

This section lists, in tabular form, a summary of all operating charges applicable to the support vessel marine terminal. No capital costs are shown since none are allocated for this subsector. The total operating cost for the entire support vessel marine terminal is $384,000 per year.

TABLE 4II-1.

SUPPORT VESSEL MARINE TERMINAL OERATING COSTS

GROUP	
Labor	$210,000
Utilities	10,000
Leases	164,000
	$384,000

Note: No capital cost incurred for this subsector.

4. Crew Training

A yearly allowance for crew training is provided. The cost of this training is $200,000 per year.

5. Marine Support Cost Summary

For a cost summary of marine support (sector 8), see Table 4II-2.

TABLE 4II-2.

MARINE SUPPORT COST SUMMARY (BASE CASE)

(in millions of 1980 U.S. $)

CAPITAL COST	
Research Vessel (Chartered)	--
Supply Vessel	1.80
Marine Terminal (Leased)	--
TOTAL	$1.80
OPERATING COST	
Research Vessel	3.50
Supply Vessel (including helicopter)	0.80
Marine Terminal	0.38
Crew Training	0.20
TOTAL	$4.88

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Appendix 4.

Part III. ON-SHORE TRANSPORTATION SLURRY PIPELINES

Part III. ON-SHORE TRANSPORTATION SLURRY PIPELINES

This appendix provides capital and operating cost estimations and related analysis for the transport by slurry pipeline of 4,500,000 short tons of wet nodules a year between the marine discharge facility and the processing plant, and between the processing plant and the waste disposal site.

1. Nodule Slurry Pipeline

The nodules will be recovered by a nodule storage basin at the port and slurrified. A decant pipeline will recycle the excess slurry water from the process plant to the marine terminal.

The distance and height difference between the marine discharge facility and the process plant are important design parameters. For a central value analysis a distance of 25 miles and a height difference of 1200 ft. will be considered.

1.1. System Determination and Design

The analysis of a slurry pipeline for the transportation of manganese nodule to the process plant is a very complex task and therefore the results of the following calculations will only provide a rough approximation.

The transportation of solid elements with a diameter more than 2 cm. is well beyond the present state of the art. In fact, a large fluid velocity will be required, resulting in excessive power requirements and erosion of the pipes (Refs. 2 and 4).

Using data from existing coal slurry pipelines, however, it is established that no problems exist even for pipes of hundreds of miles for solids with 8 mesh particle size.

As a result, nodule grinding is required at port, to reduce the size of the particles. It is expected that the transportation of the nodules in the vertical pipe, the storage and the transportation in the vessels, etc. will cause a significant degree of attrition, so that the power spent at port will be only part of the total power required to grind the nodules.

It is assumed that the maximum particle size is 8 mesh after grinding, and the concentration of solids by weight is 40% (equivalent to 28% by volume). The required fluid velocity is 5.6 ft./sec. (Ref. 1) resulting in a pipe of 18-inch inner diameter. The return pipe has a diameter of 14 inches.

The abrasion of a pipe in a flow below 10 ft./sec. is small (Ref. 2). The thickness is calculated on the basis of structural strength and corrosion. A liner is installed as corrosion inhibitor.

The pressure loss is evaluated following (Ref. 2) for heterogeneous mixtures moved by saltation. For the values above, the required horsepower is 110 HP/mile. In addition, to account for the difference in elevation, it is estimated that a power of 1.18 HP/ft. is required. For a 25-mile pipeline length and 1,200 ft. elevation, 4,200 HP is required.

Assuming 70% efficiency for the positive displacement pumps the required pump power is 5,950 HP, resulting in electric consumption of $3.3 * 10^7$ KWH/yr.

For characteristics of the pipeline, see Table 4III-1.

TABLE 4III-1.

SLURRY PIPE CHARACTERISTICS: BASE CASE

Length	=	25 miles
Height Difference	=	1,200 ft.
Nodule Concentration	=	40% by weight
Fluid Velocity	=	5.6 ft./sec.
Pipe Diameter	=	18 inches
Pump Power	=	5,950 HP
Power Concentration	=	$3.3 * 10^7$ KWH/yr.
Grinding Power	=	1,000 horsepower
Power Consumption	=	$0.55 * 10^7$ KWH/yr.

1.2. Cost Estimation Methodology

The cost calculations for the slurry piepline between port terminal and the process plant are divided into the following two subsectors:

1. Slurry Pipe and Equipment
2. Transportation Required Land

1. Slurry Pipeline and Equipment

The system is divided into capital and operating cost. The capital costs are the pipeline, the pumps and support equipment, the storage for water needed for start-up, and miscellaneous items.

The pipeline cost is determined from the cost of the pipeline (with the selected diameter) per mile. This figure includes the cost of pipe, labor, equipment, machinery, and parts. The capital cost of the pumps is determined based on the pump power required. The capital cost of the water storage is calculated directly from the needed capacity. The miscellaneous cost is taken as a percentage of the total capital cost.

The operating costs are divided into energy, labor, and maintenance costs. The labor cost is assumed to be a linear function of the length of the pipeline and maintenance is considered to be 6% of the system capital cost.

2. Slurry Pipeline Transportation Land

The amount of land necessary for rights-of-way, if conveyor, rail, or slurry pipeline methods are used, is calculated assuming a 50-foot right-of-way. A 50-foot cost for the required rights-of-way are the sum of the direct land costs plus the land survey and preparation costs. The direct land cost is equal to 6.06 acres/mile multiplied by the length of the particular right-of-way and the cost of the land per acre. The preparation and land survey cost are given as a function (i.e., in $/mile) of the particular right-of-way.

1.3. Capital and Operating Cost for Slurry Pipeline Between Process Plant and Marine Terminal

Costs are given in 1980 U.S. dollars.

1. Slurry Pipeline

The dimensioning and power requirements are calculated by the procedure given in section 1.1. The costs are given in function of the pipe diameter (see Table 4III-2). This is used for slurry pipeline and the decant pipeline.

TABLE 4III-2.

PIPE LAYING COSTS: EQUIPMENT, LABOR AND MATERIALS

Black Steel Pipe, Welded Joints

DIAMETER (Inches)	$/LFT	$/MILE
6	11.21	59,189
8	14.59	77,035
10	17.23	90,974
12	20.10	106,128
14	24.90	131,472
16	28.30	149,424
18	31.60	166,848
20	35.00	184,800
24	41.90	221,232
30	53.71	283,589
36	69.14	365,053
42	87.90	464,112

The capital cost for the pumps and equipment is in a conventional pumping installation around 22% of the pipe cost (Ref. 3). In this analysis the water reservoir for start-up procedure was not taken into account. The miscellaneous costs are assumed to be 24% of the pipe cost (Ref. 3). The total capital cost for the slurry pipeline (including the return pipeline) from the marine terminal to the process plant (25 miles, 1,200 ft. height difference) is therefore calculated to be $10.89 M.

The yearly operating costs are divided into:

Energy: Calculated at $0.06/KWH

Labor : Assuming a chief engineer and four staff engineers along with seven to eight technicians to operate the pipeline, a salary cost of $400,000 is obtained. Also, three to four men per 25 miles of pipeline are needed as field technicians and operators at a cost of $50,000.

Maintenance: Assumed to be 10% of the total capital cost.

The yearly operating cost for the pipeline (25 miles length) is $3.2 M.

2) <u>Transportation, Required Land</u>

The transportation land cost is calculated as the summation of:

Cost per acre of right-of-way land,
Cost per mile of land preparation, and
Cost per mile of surveying

A fifty-foot right-of-way land strip is assumed. This corresponds to six acres per mile. The cost of land along the waste disposal pipeline is assumed to be $1,000/acre. The cost per mile of surveying is assumed to be $200/mile. and the cost per mile of land preparation, $10,000/mile. The total capital cost for the transportation land is $400,000.

For on-shore transportation slurry pipeline cost summary, see Table 4III-3.

TABLE 4III-3. SLURRY PIPELINE COST SUMMARY
(in millions of 1980 U.S. $)

Capital Cost	$10.89
Operating Cost	3.20
Land Cost	0.40

2. Waste Slurry Pipeline

A pipeline is used to transport, in slurry form, the wastes between the processing plant and the waste disposal case. For the base case a distance of 60 miles is assumed. A decant pipeline recirculates the decant water from the waste site to the processing plant.

The maximum particle size is assumed to be 100 mesh, requiring a water velocity of 5.6 ft./sec. The pipe diameter is 16 inches assuming a 50% concentration by weight.

The same procedure as in the case of the port-plant pipeline is used. An elevation of 1,900 ft. is assumed and a return pipeline is included.

The power required is 80 HP/mile and 1.2 HP/ft. of elevation resulting in 7,100 HP. The pump power assuming a 75% efficiency is 9,500 HP, divided between two pump stations, one at the plant and one midway between the plant and the waste disposal area.

The capital cost of the pipe, including a return pipe and the pumps, is estimated at $22.4 M.

The yearly operating costs include the energy cost, labor cost, and maintenance costs as described in the previous sections. The total annual cost is $4.48 M.

The cost of the land is evaluated with the same assumptions as before, arriving at a cost of $0.96 M.

For cost summary, see Table 4III-4.

TABLE 4III-4. WASTE SLURRY PIPELINE COST SUMMARY
(in millions of 1980 U.S. $)

Capital Cost	22.40
Operating Cost	4.48
Land Cost	0.96

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APPENDIX 5. PROCESSING

There are several metallurgical processing techniques that can be used to extract and refine the copper, nickel, and cobalt in deep sea nodules. These techniques include reduction/ammoniacal leaching, cuprian/ammonia leaching, high temperature sulfuric acid leaching, reduction/hydrochloric acid leaching, and smelting. For illustrative purposes, costs have been estimated for a plant using the reduction/ammoniacal leach process described in Dames and Moore (1977).

This sector includes all the operations in the processing plant, from receiving the nodules and other raw materials to shipping the metal products and preparing the tailings for disposal. The pipeline transporting the nodules from the shore facility to the plant, and the tailings pipeline and disposal area are not included in the cost estimate of this sector.

The capital and annual operating costs presented in this appendix are in March 1980 U.S. dollars and are for a plant that processes 3 million short tons of dry nodules -- 4.5 million tons wet -- per year. An important caveat must be made with regard to using these cost estimates. The processing plant is an extremely complex unit and as a consequence, the costs given in this study should not be manipulated to derive the cost of a plant that is significantly different in size or type than the one described below.

1. Methodology of Capital Cost Estimation

No processing plant such as the one assumed in this study has ever been built before, but each of the component technologies have been proven in other plants. Since most every piece of equipment in this operation exists in various other chemical and metallurgical plants, costs can be estimated for each piece or grouping of equipment. Capital costs of the reduction/ammoniacal leach plant are estimated by the scaling and aggregation of appropriate equipment costs found in engineering and cost estimation literature. The general methodology for capital cost estimation of the processing sector is as follows:

1) The processing plant is divided into subsectors and sub-sub-sectors which correspond to the functional working

units of the plant. The subsectors are:

1. Materials, Storage, Handling, and Preparation
2. Nodules Reduction and Metal Extraction
3. Metals Separation
4. Reagent Recovery and Purification
5. Metals Recovery and Purification
6. Plant Services

Each of these is further divided into sub-subsectors which are described in the next section.

2) The sub-subsectors are divided into units for which costs can be derived. The equipment composition of these units is determined by the availability and accuracy of cost data. Thus, some of the cost units are individual pieces of equipment and others are large groupings of equipment.

3) The size or capacity of each cost unit is derived from the material balances in the Dames and Moore report. Sizing and specification criteria (e.q., throughput, storage capacity, diameter, power, construction materials, etc.) are chosen according to how the unit is described in the cost literature and may be revised as better information becomes available.

4) Once the sizing and specification criteria of a unit are known, that unit's cost can be estimated from cost estimating or process engineering literature. All costs are updated to 1980 dollars using the Marshal and Swifts index (M&S). This index equaled 640 in 1980.

5) Costs for units that correspond to individual pieces of equipment usually come in one of two forms: purchased equipment costs, or installed equipment costs. Purchased equipment cost estimates are multiplied by 1.4 to account for installation charges, so that they are put on an equivalent basis with installed equipment costs.

6) Some cost units contain many pieces of equipment along with all of the auxiliaries required to keep them functional. Sectionalized costs are usually obtained for these units. In addition to equipment costs and installation charges, sectionalized costs include charges for auxiliaries such as instrumentation, piping, electrical connections, buildings, yard improvements, and services.

These types of auxiliaries charges are allocated to individual pieces of equipment by multiplying the installed equipment costs (or factor derived equivalents) of these units by 1.9. This puts individual equipment costs on an equivalent basis as sectionalized costs.

7) Sectionalized costs (or their factor derived equivalents) are aggregated to the sub-subsector level. In other words, each sub-subsector is given a cost that includes charges for all its equipment, installation, and accompanying auxiliaries. This is known as the sub-subsector physical plant cost.

8) The total physical plant cost is calculated by adding all of the sub-subsector physical plant costs together. This sum is multiplied by 1.5 to cover indirect costs such as engineering and construction costs, contractors' fees, and a contingency cost (i.e., indirect costs are 50% of the total physical cost). The product is known as the fixed capital investment for the processing sector.

The factors 1.4, 1.9, and 1.5 are derived from experience in estimating typical chemical process plant costs. Each has been developed such that its underlying components and assumptions are appropriate for the plant layout assumed in this study.

Figure 5-1 shows the typical components of these factors for a hypothetical cost unit that has a purchased equipment cost of $1000. The charge for installation of this piece of equipment is $385. The installed equipment cost is therefore $1385. Using the factor approach, the installed equipment cost is estimated to be $1400 (i.e. 1000 x 1.4).

This type of equipment also has auxiliaries charges allocated to it. These charges are; $132 for instrumentation, $215 for piping, $178 for electrical connections, $354 for buildings, $98 for yard improvements, and $274 for services. Auxiliaries charges brings the unit's contribution to the sub-subsector physical plant cost to $2636. The factor approach estimates this contribution to be $2660 (i.e. 1400 x 1.9).

Indirect costs such as $400 for engineering and supervision, $446 for construction expenses, $92 for contractors' fees, and $378 for contingency fees bring the unit's contribution to the fixed capital investment of the processing sector to $3952. The factored

FIGURE 5-1: BASIS FOR TYPICAL FACTORS USED TO ESTIMATE COST LEVELS[1]
(Hypothetical piece of equipment with $1000 purchased equipment cost)

Contribution to Fixed Capital Investment

Contribution to Physical Plant Cost

Installed Equipment Cost

Purchased Equipment Cost $1000 + Installation = $385

Total = $1385

(factored estimate = 1.4 x 1000 = $1400)

+ Instrumentation	= $ 132
Piping	= 215
Electrical connections	= 178
Buildings	= 354
Yard improvements	= 98
Services[2]	= 274
Total	= $2636

(factored estimate = 1.9 x 1400 = $2660

+ Engineering & Supervision	= $ 400
Construction expenses	= 446
Contractors' fees	= 92
Contingency fees	= 378
Total	= $3952

(factored estimate = 1.5 x 2660 = $3990)

(1) Source: Peters M.S. and K.D. Timmerhaus, *Plant Design and Economics for Chemical Engineers*, (1968)

(2) This factor has been reduced because certain components of the service category have been estimated directly.

estimate of this contribution is $3990 (i.e. 2660 x 1.5).

These factors are averages used for estimation purposes only. The factors are not necessarily appropriate for a specific piece of equipment but are valid averages for all the equipment in the plant.

The validity of this estimating procedure rests on the ability to draw analogies to well documented costs for similar types of construction. Uncertainties of plus or minus 25% are inherent in this estimation methodology.

2. Capital Cost Estimates

Costs presented in this section are estimates of the sub-sub-sector physical plant costs and indirect costs for all equipment within the battery limit of the plant. No costs are incurred for any development outside of the plant, because the necessary infrastructure is assumed to be already in place. This infrastructure includes electric and water utilities; qualified manpower; accessible road, rail, and air transportation networks; police and fire protection; business services such as office and building supplies, vendors as well as food and maintenance services; and housing, hospitals, and recreation facilities for employees.

This section describes each of the sub-subsectors and explains the purpose of each in the overall process. The flowchart in Figure 5-2 shows how the sub-subsectors fit into the processing sequence of the plant. (The sector numbering in fig 5-2 reflects the processing sector's place in the overall model, that is sector 6.)

Physical plant costs, for a plant with processing capacity of 3 million short tons of dry nodules per year, are given for each of the sub-subsectors. The indirect costs are factored in last, and the fixed capital investment of the processing sector is given in Table 5-1.

2.1 Material Storage, Handling, and Preparation

2.1.1 Rail Car Station

Most of the large volume raw materials except the nodules are transported to the plant by rail. The rail car station has the capacity to receive 775,000, 9300, and 26,400 tons per year of coal, lime, and limestone respectively. This facility includes a dumping station with feeders, conveyors, hoppers, and a station building.

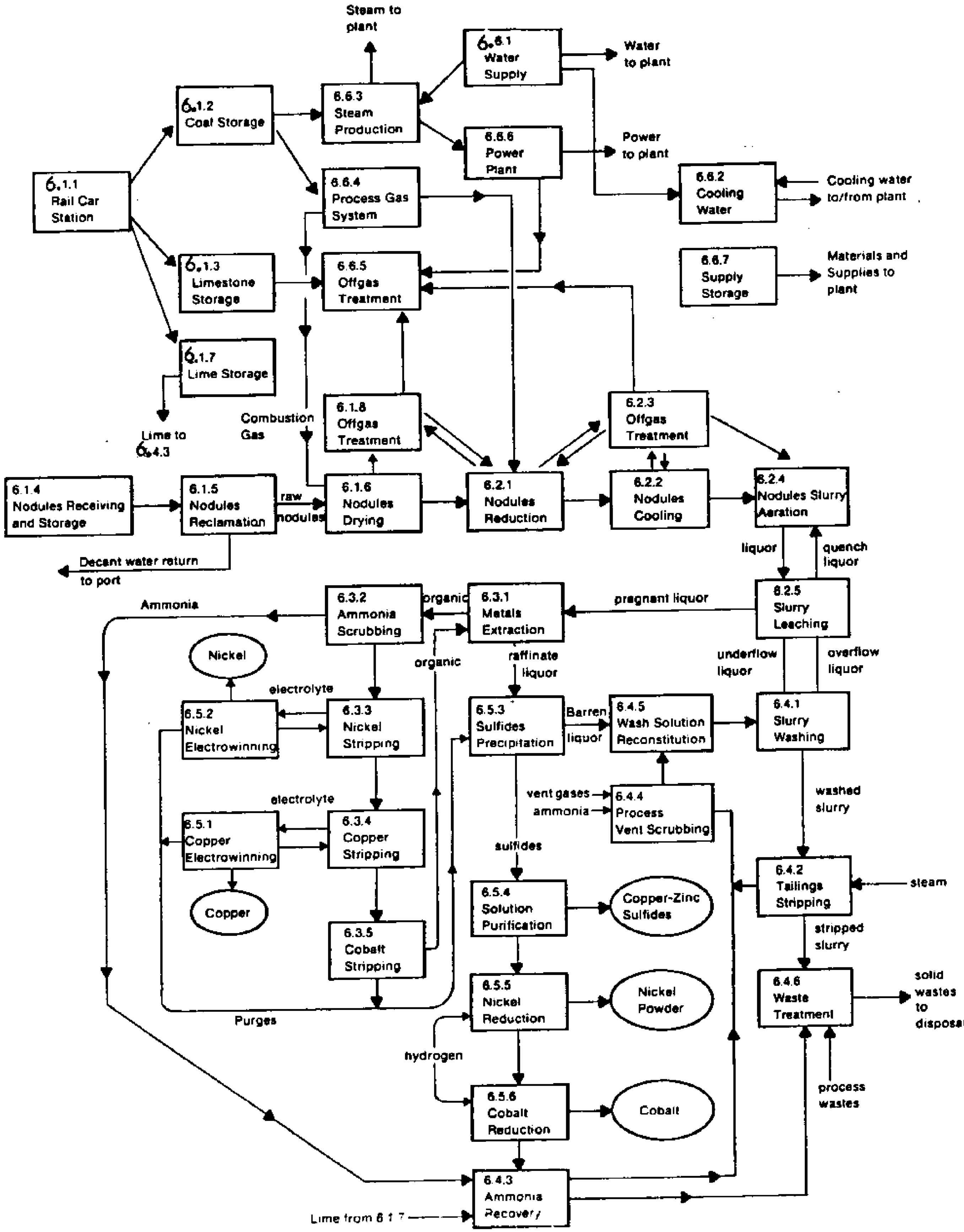

FIGURE 5-2 PROCESSING SECTOR

The physical plant cost (PPC) is estimated to be $1.4 million.

2.1.2 Coal Stacking, Storage, and Reclamation

Coal is used in this plant for boiler fuel and reduction gas production. The coal enters the plant through the rail car station, and is stacked in piles until reclaimed for use in the process. This system handles 775,000 tons of coal per year and provides storage capacity for 4 months supply of coal. Required equipment includes conveyors from the rail car station to the storage area, a stacker-reclaimer at the storage pile, conveyors to the coal preparation equipment at the boilers and coal gasifiers, trippers, trip conveyors, and dust control facilities. PPC = $5.2 million.

2.1.3 Limestone Stacking, Storage, and Reclamation

Limestone is used in the plant for desulferizing combustion and reduction gases. Except that the equipment is much smaller, the same general sort of transfer and reclamation system as described in 2.1.2 is used to handle 26,400 tons of limestone per year, and provide 60 days of storage capacity. Required facilities include transfer and tripper conveyors and accessories, reclamation and feeding equipment, a dust control system, and a storage building. PPC = $1.8 million.

2.1.4 Nodules Receiving and Storage

The nodules come to the plant through a slurry pipeline and are distributed and held in storage ponds until they are needed. This system handles 4,125,000 tons of nodules per year and has a storage capacity of 120 days. Transport slurry water is drained from the storage ponds, pumped to a decant pond, and held there until returned to the port for use in reslurrying fresh nodules for transport to the plant. The decant pond has a holding capacity for one week's water drainage. PPC = $19.0 million.

2.1.5 Nodules Reclamation and Transfer

The nodules are reclaimed from the storage ponds with cutter head dredges and are transferred to the grinding and drying equipment on a conveyor. PPC = $4.6 million.

2.1.6 Nodules Grinding and Drying

The nodules are ground and dried at relatively low temperature before being fed to subsequent reduction operations. The grinding and drying circuit includes mill and dryer feed bins, feeders and conveyors, primary and secondary cage mills, fluid bed dryers fitted with primary cyclones, and secondary mill classification blowers. PPC = $7.1 million.

2.1.7 Lime Storage and Slaking

Slaked lime is used to free ammonia from the ammonium sulfate that is produced in the liquid ion exchange circuit and the cobalt recovery system. The ammonia can then be reused throughout the plant. The transfer and storage is similar to the one used for limestone, except that it is smaller and includes a slaker. Equipment in this system handles 9300 tons of limestone per year and has a storage capacity for 60 days supply. PPC = $1.1 million.

2.1.8 Offgas and Fugitive Control Equipment

The offgas from the secondary mill and fluid bed dryers must be treated to return nodules fines to the process, remove dusts, and control fugitive emission. These operations are performed with secondary cyclones, electrostatic precipitators, gas blowers, and dried nodules collection, storage, and transfer equipment. PPC = $11.0 million.

2.2 Nodules Reduction and Metal Extraction

2.2.1 Dried Nodules Feeding and Reduction

The manganese oxide in the dried nodules is reduced with high temperature producer gas. This reduction disrupts the nodules' structure which makes the metals easier to extract in subsequent operations. 2.8 million tons of nodules per year are reduced in fluid bed roasters with producer gas from the coal gasification plant. Equipment required for this operation includes a two-stage fluid bed reduction roaster with the necessary hoppers, conveyors, feeders, and primary and secondary cyclones. PPC = $6.7 million.

2.2.2 Reduced Nodules Cooling

In preparation for subsequent leaching operations, the reduced nodules are cooled by direct contact with water sprays in a fluid bed cooler. Required equipment includes the fluid bed cooler with necessary solids transfer equipment, primary and secondary cyclones, and cooled reductant gas circulation blowers. PPC = $6.8 million.

2.2.3 Offgas Treatment

Bag filters, cyclones, electrostatic percipitators, gas blowers, and a waste heat boiler are used to remove dust and heat from the effluent gases that come from the roasters (2.2.1) and the coolers (2.2.2). The dust is returned to the process stream, and the heat is employed in the production of low pressure steam used elsewhere in the plant. PPC = $6.0 million.

2.2.4 Reduced Nodules Slurry Aeration

The still warm nodules particles are quenched in recycled leach liquor, and the resulting slurry is then aerated to partially dissolve the value metals and precipitate out the iron as an oxide. 5600 gallons of liquor per minute are circulated through this system which includes an agitated quench tank, covered agitated aerators, and slurry transfer pumps. PPC = $1.8 million.

2.2.5 Nodules Slurry Leach

Final dissolution of the value metals into the leach liquor and separation of this pregnant liquor from nodule residues takes place in a counter-current thickner circuit. The thickeners are covered to prevent loss of ammonia vapor. Necessary equipment includes the thickener assemblies, overflow and underflow pumps, a heat exchanger, a pregnant liquor surge tank, and transfer pumps. PPC = $13.0 million.

2.3 Metals Separation

The metals dissolved in the pregnant liquor, obtained from the separation thickeners, must be separated from each other. This is done by extracting out each metal independently (i.e., selective extraction). The liquor is not a good medium for this separation method, so the dissolved metals are transferred to a liquid ion exchange (LIX) resin, before the metals are selectively extracted. The transference and selective extraction is performed by the five subsubsectors of the Metals Separation subsector:

2.3.1 Metals Extraction transfers most of the copper and nickel, and some of the ammonia and cobalt, from the liquor to the organic LIX medium.

2.3.2 Ammonia Scrubbing removes the ammonia from the organic. The ammonia is then recycled.

2.3.3 Nickel Stripping removes nickel from the organic. The nickel is then sent via electrolyte to be recovered and purified in the nickel electrowinning section.

2.3.4 Copper Stripping removes copper from the organic. The copper is then sent via electrolyte to be recovered and purified in the copper electrowinning section.

2.3.5 Cobalt Stripping and Solution Recovery prepares the organic exchange medium for reuse by removing small amounts of an impure cobalt mixture. This mixture is then sent to a series of equipment designed to purify the cobalt, and recover other metals, through a more sensitive selective extraction process.

These five operations are done in an 11-stage LIX circuit that handles 1350 gallons of pregnant liquor and 2700 gallons of organic per minute. Necessary equipment includes mixer settler units, filters, surge tanks, transfer pumps, solvent and ammonia recovery hardware, heat exchangers, and cobalt removal reactors. PPC = $30.0 million.

2.4 Reagent/Recovery and Purification

2.4.1 Leached Slurry Washing

The tailings slurry, produced in Nodules Slurry Leaching-Separation (2.2.5) is washed in a five stage counter-current decantation circuit to ensure that all valuable dissolved metals are recovered. The washing process yields metal containing liquors and barren tailings, which are sent to the leaching sections (2.2.5) and Washed Tailings Stripping (2.4.2) respectively. 1360 gallons of slurry per minute is washed in this circuit which includes covered thickeners with underflow and overflow pumps. PPC = $21.9 million.

2.4.2 Washed Tailings Stripping

Barren tailings, from the Slurry Washing circuit (2.4.1), contain ammonia and ammonium carbonate which must be recovered. These ammonia reagents are stripped from the tailings and passed to Process Vent Scrubbing (2.4.4) for recycling treatment. The ammonia-free tailings are sent to Waste Treatment (2.4.6) to be prepared for disposal. Equipment in this stripping operation, which handles 1360 gallons of tailings per minute, includes an agitated tailings surge tank, stripping tower, energy recovery exchanger, stripped tailings coolers, and transfer pumps. PPC = $1.5 million.

2.4.3 Ammonia Recovery-Lime Boil

The ammonium sulfate, produced by Ammonia Scrubbing (2.3.2) and Cobalt Reduction (2.5.6), is reacted with slaked lime to produce ammonia and gypsum. The ammonia is sent to storage for reuse and the gypsum waste product is sent to Waste Treatment (2.4.6). Equipment in this recovery operation, which processes about 35 gallons of ammonium sulfate solutions per minute, includes a storage tank with agitator, lime boil vessel, slurry cooler, heat exchanger, and transfer pumps. PPC = $0.9 million.

2.4.4 Process Vent Scrubbing-Ammonia and Carbon Dioxide

Ammonia and carbon dioxide are recovered from the vent gases of various pieces of equipment throughout the plant and from the ammonia reagents produced by Washed Tailings Stripping (2.4.2). 500 standard cubic feet (scf) per minute of carbon dioxide from the plant boilers and 33,000 scf per minute of various vent gases are treated in the scrubbing equipment which includes an ammonia absorber/condenser, a carbon dioxide absorber, an ammonia absorber, a vent scrubber, transfer and recirculation pump, heat exchangers, and blowers. PPC = $3.8 million.

2.4.5 Washing Solution Reconstitution and Recycle

The leach liquor cycle starts at Slurry Washing (2.4.1) and progresses through Slurry Leaching (2.2.5), Metals Extraction (2.3.1) and Sulfides Precipitation (2.5.3). The barren liquor is then rejuvenated with carbon dioxide and ammonia from the Vent Scrubbing section (2.4.4) and run back through the cycle. This reconstitution and recycle operation handles 2720 gallons of liquor per minute in equipment which includes a raffinate storage tank, agitators, and pumps. PPC = \$0.3 million.

2.4.6 Waste Slurry Storage, Treatment, and Transfer

The processing plant produces 1900 gallons per minute of waste slurries and smaller amounts of miscellaneous solid and liquid process waste and plant run off. These wastes are treated in an agitated slurry tank with the necessary transfer pumps. There is also an emergency dump surge pond equipped with a single dredge head slurry reclaimer in case permanent disposal is delayed for some reason. PPC = \$1.9 million.

2.5 Metals Recovery and Purification

2.5.1 Copper Electrowinning

Copper in the loaded electrolyte received from Copper Stripping (2.3.4) is reduced and deposited onto copper cathodes, known as starter sheets, in commercial electrowinning cells. The cathodes, laden with freshly deposited copper, are then washed and prepared for sale, while the electrolyte is returned to Copper Stripping for reloading.

Along with commercial and stripper cells, the electrowinning plant includes necessary tankage, pumps, and rectifiers as well as facilities for additives preparation, starter sheet preparation, nickel remover, and cathode handling. Also, the tankhouse is equipped with sumps to contain spills and collect slimes for disposal. PPC = \$22.5 million.

2.5.2 Nickel Electrowinning

The nickel electrowinning plant is similar to the copper one, except that it produces nickel instead of copper and it includes facilities for cathode bag handling, electrolyte purification, and cobalt removal. PPC = \$32.7 million.

2.5.3 Mixed Sulfides Precipitation and Separation

Ammonium hydrosulfide is used to precipitate cobalt, zinc, and the remaining copper and nickel from the LIX raffinate produced in Metals Separation (2.3.1). The metal-sulfide precipitates are separated from the raffinate and the clarified solution is sent to be rejuventated in Wash Solution Reconstitution (2.4.5). The sulfide precipitates, together with copper and nickel from the electrowinning circuits and cobalt from Cobalt Stripping (2.3.5) are sent to be refined in Solution Purification (2.5.4). 1350 gallons of raffinate per minute are processed in this manner with equipment which includes tankage, an ammonium sulfide reactor, a cobalt sulfide precipitator, a clarifier with a filter, heat exchangers, agitators, and pumps. PPC = $2.9 million.

2.5.4 Selective Leaching and Solution Purification

The sulfide mixture, produced in Sulfides Precipitation and Separation (2.5.3), is pressure leached and filtered to separate the sulfides. The cobalt and nickel sulfides are sent to Nickel Reduction (2.5.5) for further refining, while 2400 tons of copper-zinc sulfide per year are sold to smelters for further processing. Required equipment includes a flash vessel, a selective leach reactor with agitator, filters, tanks, heat exchangers, and pumps. PPC = $1.3 million.

2.5.5 Nickel Reduction and Sintering, Solution Repurification

The nickel sulfide is separated from the cobalt sulfide by autoclaving and selective reduction of the nickel sulfate with hydrogen. 700 tons of nickel powder per year are produced, sintered, and packaged in equipment which includes a flash vessel, a nickel reduction reactor with agitator, tanks, agitators, heat exchangers, filters, and pumps. PPC = $1.1 million.

2.5.6 Cobalt Reduction and Sintering

Cobalt sulfate solution, the product of (2.5.3), (2.5.4), and (2.5.5) is purified (i.e., contaminant nickel is removed) by pH controlled selective precipitation of nickel salts in a nickel and cobalt rich ammonia solution. Once the solution is adequately purified, the solution is autoclaved and the cobalt sulfate is reduced with hydrogen. The cobalt powder is then sintered and packaged. 4300 tons of cobalt powder per year are produced in equipment which includes an evaporator/crystallizer, centriguge, oxidation reactor, crystallizer, reduction reactor, sintering and packaging machines, tanks, agitators, heat exchangers, filters, and pumps. PPC = $2.9 million.

2.6 Plant Services

2.6.1 Water Supply, Purification, and Distribution

Water is needed throughout the plant for various direct process purposes, as well as for cooling tower and boiler requirements. 3250 gallons per minute of process water and 50 gallons per minute of potable water are provided using a pumping station, gravity filtration unit, hot line process softener, potable water treatment unit, and necessary pumps and tankage. PPC = $5.9 million.

2.6.2 Cooling Water System: Towers, Circulation, and Treatment

The temperature of cooling water increases as it is circulated throughout the plant. Heat is removed by evaporation during passage through forced draft cooling towers. Tower blowdown is used to quench gasifier ash. This system includes towers, basins, fans, and circulation pumps. PPC = $3.7 million.

2.6.3 Process Steam System

Various heating and stripping operations, coal gasification, and power cogeneration all require steam. 500,000 lbs of steam per hour (at 1000 psi) is provided for these functions by a steam plant consisting of dual 60 percent capacity pulverized coal fired boilers, coal handling and ash removal equipment, a condensate and feedwater treatment system, hot electrostatic precipitator, air heater and a building. PPC = $33.2 million.

2.6.4 Process Gas System

Producer gas for nodule reduction and combustion gas for nodule drying are produced in dual two-stage entrained flow gasifiers in which coal is mixed with preheated air and high temperature steam. These gasifiers, which produce 8.7 million scf of low BTU gas per hour, require coal storage and handling equipment, but not sulfur removal and recovery facilities. Sulfur emissions are controlled by Offgas Treatment (2.6.5) PPC = $30.1 million.

2.6.5 Offgas Treatment

Offgases from the boiler, nodules drying and reduction facilities, and process vents are treated in desulferization, sludge removal, and gas reheat equipment. There is also a stack capable of handling 705,000 scf of gas per minute. PPC = $5.6 million.

2.6.6 Plant Power Generation and Distribution

The processing plant uses 48,600 KW of electricity; 23,500 is purchased from a utility, and 21,500 KW is produced using steam from the boiler and a back pressure turbine generator set. Other required electrical equipment includes transformers and a switching, control, and distribution system. PPC = $6.7 million.

2.6.7 Storage: Process Materials, Supplies, Fuels, and Products

An inventory of raw materials is kept on hand so that the process is not susceptible to supply disruptions and can be kept running throughout the year. A 5000-square-foot building is needed for storage of solids used in the process. Also storage must be provided for 3 days of hydrogen gas; 30 days of gaseous hydrogen sulfide, ammonia, and chlorine, as well as liquid LIX organic and sulfuric acid; and 120 days of fuel. All supplies are brought to the plant periodically by road or rail except hydrogen, which is purchased "over the fence" from a small plant nearby. PPC = $4.3 million.

Table 5-1 is a summary of all the sub-subsector physical plant costs[1]. The total physical cost is $298.7 million and the total fixed capital investment is $449.1 million. This latter figure includes $1000 land cost (500 acres at $2/acre).

Table 5-1 Capital Cost Summary

(In Millions of 1980 U.S.$)

		Physical Plant Cost (PPC)
2.1	MATERIAL STORAGE, HANDLING, AND PREPARATION	
.1	Rail Car Station	1.4
.2	Coal Stacking, Storage, and Reclamation	5.2
.3	Limestone Storage, Stacking, and Reclamation	1.8
.4	Nodules Receiving and Storage	19.0
.5	Nodules Reclamation and Transfer	4.6
.6	Nodules Grinding and Drying	7.1
.7	Lime Storage and Slaking	1.1
.8	Offgas and Fugitive Control Equipment	11.0
	Total:	51.2
2.2	NODULES REDUCTION AND METAL EXTRACTION	
.1	Dried Nodules Feeding and Reduction	6.7
.2	Reduced Nodules Cooling	6.8
.3	Offgas Treatment	6.0
.4	Reduced Nodules Slurry Aeration	1.8
.5	Nodules Slurry Leaching - Separation	13.0
	Total:	34.3
2.3	METALS SEPARATION	
	Liquid Ion Exchange Plant	30.0
2.4	REAGENT RECOVERY AND PURIFICATION	
.1	Leached Slurry Washing	21.9
.2	Washed Tailings Stripping	1.5
.3	Ammonia Recovery - Lime Boil	0.9
.4	Process Vent Scrubbing - NH_3 and CO_2	3.8
.5	Wash Solution Reconstitution and Recycle	0.3
.6	Waste Slurry Storage, Treatment, and Transfer	1.9
	Total:	30.3
2.5	METALS RECOVERY AND PURIFICATION	
.1	Copper Electrowinning	22.5
.2	Nickel Electrowinning	32.7
.3	Mixed Sulfides Precipitation and Separation	2.9
.4	Selective Leaching and Solution Purification	1.3
.5	Nickel Reduction and Sintering, Solution Repurification	1.1
.6	Cobalt Reduction and Sintering	2.9
	Total:	63.4
2.6	PLANT SERVICES	
.1	Water Supply, Purification and Distribution	5.9
.2	Cooling Water System; Towers, Circulation and Treatment	3.7

		Physical Plant Cost
	PLANT SERVICES (continued)	
.3	Process Steam System	33.2
.4	Process Gas System	30.1
.5	Offgas Treatment	5.6
.6	Plant Power Generation and Distribution	6.7
.7	Storage; Process Materials, etc.	4.3
	Total:	89.5
	Total Physical Plant Cost (TPPC)	298.7
	Indirect Costs (@ 50% TPPC)	149.4
	Land	1.0
	Total Fixed Capital Investment	449.1

3. Annual Operating Costs

In addition to capital costs, the plant will incur annual costs such as direct production and overhead costs, fixed charges, and administrative, distribution, and marketing expenses. Together, these annual costs are known as the Annual Operating Cost. This section estimates the annual processing cost as the sum of: 1) Materials and Supplies Costs, 2) Utilities and Fuels Costs, 3) Labor Costs, and 4) Capital Related Charges.

3.1 Materials and Supplies Costs

The costs of materials and supplies were estimated using yearly consumption rates and current prices. Yearly consumption rates are derived from the materials balances in the Dames and Moore report. Charges for each of the materials and supplies is given below.

These costs are summarized in Table 5-2.

3.2 Utilities and Fuel Costs

As with materials and supplies, yearly consumption of utilities and fuels was derived from Dames and Moore. The yearly costs of these items are shown on the next page. The charge to power is the cost of the electricity that the plant needs but does not generate for itself.

TABLE 5-2

MATERIALS AND SUPPLIES

Cost Summary
(In Thousands U.S. $)

Materials and Supplies		Annual Cost
$CaCO_3$	26.4M TPY @ $20/T	528
CACO	9.3M TPY @ $32.5/T	302
NH_3	4.0M TPY @ $190/T	760
H_2S	4.9M TPY @ $200/T	980
H_2	96MM SCFY = 32.6 MMM BTU/yr @ $10/MM BTU	326
Cl_2	100 TPY @ $145/T	15
H_2SO_4	670M GPY =5.1M TYP @ $70/T	357
Na_2SO_4	1350 TPY @ $62/T	84
H_3BO_3	200 TPY @ $506/T	101
NaCl	230 TPY @ $67/T	15
C	40 TPY @ $400/T	16
LIX Reagents 75M GPY:	15M GPY LIX @ $23/gal	345
	60M GPY Kerosene @ $1/gal	60
Flocculants	2000 lb/yr @ $2/lb	4
EW Additive	16 TPY @ $500/T	8
H_2O Treatment	180 TPY @ $500/T	90
	TOTAL MATERIALS & SUPPLIES	3,990

TABLE 5-3

UTILITIES AND FUELS COST SUMMARY

Utilities and Fuels		Annual Cost (In Thousands of U.S. $)
Coal	775 M TYP @ $45/T ($2/MM BTU)	34,875
POL (Petroleum Products)	500M GPY @ $1/gal	500
H_2O	1580MM GPY @ $0.55/M gal	870
Power	188MM kWh @ $0.06/kWh	11,280
	TOTAL UTILITIES AND FUEL	47,520

3.3 Labor Costs

The nodules plant is estimated to employ about 500 people. The breakdown of this figure into general occupations and the accompanying salaries is given below.

TABLE 5-4

LABOR COST SUMMARY

(In Thousands of U.S. $)

Labor		Annual Cost
50 Management & Tech/Prof. Staff	@ $40M	2,000
50 Clerical & Administrative	@ $20M	1,000
50 Operating & Maintenance Supervision	@ $30M	1,500
50 Senior Operators & Maintenance Pers.	@ $25M	1,250
250 Operators & Maintenance	@ $20M	5,000
50 Plant & Operations Support	@ $15M	750
Total Direct Salaries (TDS)		11,500
Fringes (@ 45% TDS)		5,180
TOTAL LABOR COSTS		16,680

3.4 Capital Related Charges

Some types of costs, such as overhead and fixed charges, are best estimated as a percentage of the Fixed Capital Investment (FCI). These charges are shown below. Maintenance Materials refers to the replacement of wornout machinery. Operating Supplies refers to general tools, janitorial supplies, etc. The other categories are self explanatory. Patent and royalty fees incurred by the processing plant are assumed to be insignificant. If this assumption is inaccurate, these fees would be estimated as a capital related charge.

TABLE 5-5

CAPITAL RELATED COSTS SUMMARY

(In Thousands of 1980 U.S. $)

Capital Related Costs (on 449.0 Fixed Capital Investment)		Annual Cost
Maintenance Materials	@ 4% FCI	17,960
Operating Supplies	@ 1% FCI	4,490
State/Local Taxes	@ 1% FCI	4,490
Insurance	@ 1% FCI	4,490
TOTAL CAPITAL RELATED CHARGES		31,430

3.5 Annual Operating Costs Summary

Table 5-6 summarizes the major categories of annual processing costs. The total annual processing cost is nearly $99.5 million.

TABLE 5-6

ANNUAL OPERATING COST SUMMARY

(In Thousands of 1980, U.S. $)

Materials and Supplies Costs	3,990
Utilities and Fuel Costs	47,520
Labor Costs	16,680
Capital Related Charges	31,430
	99,620

4. Summary

The fixed capital investment for a nodules plant that processes 3 million short tons of dry nodules per day by the reduction/ammoniacal leach methods is $449.1 million (1980). An uncertainty of plus or minus 25 percent is associated with this estimate. The Total annual processing cost for such a plant is $99.6 million.

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Appendix 6. Waste Disposal

This appendix provides capital and cost estimation and related analysis of a typical waste treatment and disposal system for a plant that processes three million short tons of dry nodules per year.

For central value analysis, a wet disposal method with minimal treatment is selected. No additional treatment of the waste before disposal is used. Wet disposal of nodules process waste is based on the use of a slurry pipeline to transport wet waste from the process plant to tailing ponds at the waste disposal site. These tailing ponds are lined. The excess transport water is decanted at the slurry ponds and overflows to a decant pond where some of the water is allowed to evaporate. The balance is returned through a smaller pipeline to the process plant to be reused.

The following assumptions were used for cost estimation:

- -- The disposal site consists of a series of disposal ponds, each of sufficient size to hold one year's waste production
- -- The maximum pond depth is 40 feet (Ref. 2)
- -- The excavation volume is two-thirds of the waste volume.
- -- The total disposal area is assumed to be 1.2 times the pond area. This is to account for the berms and retaining dikes, roadways, and administrative areas.
- -- The ponds have a square horizontal cross-section with sloping sides of about 30 degrees.

The return of decant water involves the use of a decant pipeline to the plant, where the water is reused as transport water for the waste slurry (see Appendix 4, Part III, On-Shore Transportation Slurry Pipelines).

In performing this transport water analysis it has been assumed that the slurry will settle to a final density of (about) 60 percent solid by volume (Ref. 3). The amount of liner is determined by summing the bottom area of the pond and the areas of the four sides. The bottom is assumed to be square and the slides trapezoidal.

The land and capital costs at the waste site are composed of the costs of land, evaluated by using a fixed cost of land per acre; the cost of surveying the land; the cost of land development for landfill: the cost of a decant pond; the cost of the first three ponds, constructed in the first year; and auxiliary capital costs.

The cost of a pond is comprised of the cost of clearing the land, excavating, installing the liners and compacting the site. Auxiliary capital costs refer to the cost of slurry distribution system, site services, equipment, administrative facilities and reclamation of the area at the end of its life.

Operating costs include the cost of a pond per year (after the second year), labor, maintenance, and power costs.

Excavation costs for pond construction are calculated on the basis of the waste volume, while clearing, grubbing and compacting costs are based on the area required annually.

The direct landcost and the cost of surveying are respectively set equal to $ 2,000 and $80 per acre. The capital cost of the liner is estimated at $2 per square yard. The auxiliary costs are computed as the sum of the cost of office, water, and power generators.

The operating costs are divided into the liner installation cost, the yearly site preparation cost, and the auxiliary operating costs. The site preparation costs are yearly costs of site excavation (1.2 $/yd), clearing and grubbing (465 $/acre), and rolling (776 $/acre per pass, 3 passes are used).

For the base case a nodule production of 3 million dry tons of nodules are used, resulting in 90×10^6 ft.^{3} of wastes (including remaining water) annually. The land required per year of operation, based on the assumption above, is 65 acres.

The land cost for 25 years of operation is $\$3.25 \times 10^6$. The cost for landfill and the decant pond is $\$1.5 \times 10^6$. The cost for equipment such as trucks, bulldozers, and auxiliary equipment is set at $\$0.5 \times 10^6$. The cost for surveying is (25 years) $\$ 0.13 \times 10^6$. The cost per pond includes the liner cost at $\$0.54 \times 10^6$, liner installation $6,500, excavating at $\$2.54 \times 10^6$, and clearing grubbing, and rolling at $\$0.2 \times 10^6$. The total cost is estimated at $\$ 3.3 \times 10^6$ per pond.

Initially (first year) 3 ponds will be constructed. Starting from the third year one additional pond will be prepared so that at all times two ponds are available. The operating cost includes power, personnel, and other cost estimated at $\$0.3 \times 10^6$.

For cost summary, see Table 6-1.

TABLE 6-1

WASTE DISPOSAL COSTS BASE CASE

(In millions of 1980 US $)

CAPITAL AND LAND COSTS	
Land Cost (25 years)	3.25
Landfill and decant pond	1.50
Equipment and auxiliary	0.50
Surveying	0.13
Three initial ponds	9.90
TOTAL CAPITAL AND LAND COST	15.28
OPERATING COSTS	
FIRST AND SECOND YEAR	
0 ponds	0.00
Power, materials and supplies	0.30
Labor	0.30
TOTAL	0.60
THIRD AND SUBSEQUENT YEARS	
1 pond	3.30
Power, materials and supplies	0.30
Labor	0.30
TOTAL	3.90

REFERENCES

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Appendix 7. ECONOMIC RETURN ANALYSIS

This appendix provides additional discussion of several of the various changes made in selected parameters to arrive at the "upside" and "downside" sets of assumptions presented in Chapter IV. (The material is from Will, Note 3, Ch. 4).

1. Price Forecast Values

Price forecasts are developed upon a base price and a real growth rate. Table 7-1 summarizes the ranges of a series of recently available estimates for these two price components. The table ignores the real decline in cobalt and nickel price projected by Wright for the years 1990-1995, as this affects only 2.25 out of 25.25 years of full-scale mining. In addition, simple extrapolations (see Pittman, 1980) which were made on individual metals and composite nodule prices were not considered because they do not account for market adjustments to the increased supply. For example, it has been estimated that if 16 million dry short tons of nodules are recovered by U.S. corporations by the year 2000, net U.S. imports of the component metals would be significantly reduced. One estimate suggests that net imports of cobalt would be reduced from 97% to zero, nickel imports would be reduced from 77% to 42%, and copper imports would be reduced from 19% to 15%. The ocean-based supply, in combination with the different production costs of nodule metals (as compared with land-derived metals) would cause unique effects not accounted for in simple extrapolation techniques. These market supply effects are expected to be significant for both the nickel and the cobalt markets. Thus, any simple price extrapolations would be erroneous for these metals. The increased supply of copper is not expected to disrupt the market significantly. However, the extrapolated values for this metal were well within the range of the three studies cited and thus need not be included in Table 7-1.

Best- and worst-case scenarios for metal prices are also noted in Table 7-1. It is important to note that the methodology used in determining the best- and worst-case scenarios assumes that the metals prices revert to a trend line, despite temporary fluctuations over time. The cases selected represent the best and worst estimates, not best and worst possibilities. If the prices did not revert to this (mean) trend, then a temporary fluctuation could seriously affect future prices. The best and worst projections have been selected for the up- and downside cases presented in Chapter IV.

2. LOS Treaty Provisions and Status

Although many variations of key provisions have been considered during the LOS negotiations, the new Law of the Sea treaty appears to reflect the consensus of most of the participating nations except the U.S. and a few other states. Thus, the present treaty provides a useful standard from which a range of alternatives can be inferred. That is, the mining provisions within the treaty (if and when the treaty is ratified by the U.S.) can be expected to fall within the range of possibilities between present U.S. law and the current version of the treaty. Particularly relevant portions of the treaty are outlined in the following sections.

2.1 Financial Arrangements

Current financial arrangements contain an up-front application fee of $ 0.5M in order to secure a mining permit.

TABLE 7-1

PRICE FORECAST VALUE RANGES

Forecast [1]	1995 Price Base (1980 $)	Annual Real Growth Rate (%)	Value[2] (1980 $)	Best or Worst Case
Nickel				
Bulkley	3.29	+1.6	53.24	Best
Burrows	3.35	+1.1	49.19	
Petersen & Maxwell	-	+1.1 → +1.9	-	
Pittman	-	-	-	
Reddy	3.50-4.00	0.0	42.69 → 48.79	
Wright[3]	3.46	0.0	42.20	Worst
Copper				
Bulkley	1.14	+0.9	16.14	
Burrows	-	-	-	
Petersen & Maxwell	-	+1.1 → +1.9	-	
Pittman	-	-	-	
Reddy	1.25	0.0	15.25	Worst
Wright	1.31	+1.3	19.97	Best
Cobalt				
Bulkley	-	-	-	
Burrows	9.56	+0.7	130.69	Best
Petersen & Maxwell	-	-	-	
Pittman	4.67-6.86	+0.3 → +2.1	59.72 → 123.61	Worst
Reddy	5.25-6.00	0.0	64.04 → 73.19	
Wright[3]	6.21	0.0	75.75	

1. For references to these forecasts, see Table XIV in Will *supra* note 7, Chapter I.
2. Value is calculated as the present value of a 25-year annuity valued at the price base which has constant annual growth equal to the real growth rate.

$$PV = \left(\frac{\text{Price Base}}{r - g}\right) - \left(\frac{\text{Price Base}}{r - g}\right)\left[\frac{1}{(1 + r)^t}\right]$$

3. Wright has predicted that growth will level off in 1995.

This permit must be obtained prior to commercial operations. A $1.0 M fixed charge (creditable against royalty payments) is levied during each year of commercial operation. Finally, the miner may select either of two forms of additional payments. The first alternative is to pay only production charges (royalties) equal to 5% of the gross revenues from processed metals during the first ten years of production and 12% of gross revenues during each of the remaining years of production. The second alternative is to pay a combination of royalties and profit sharing. Under this alternative, the miner pays royalties equal to 2% of gross revenues each year until the mining development costs are covered by the operation's cash surplus (this period is referred to as the "first period"). After this point (referred to as the "second period"), the mining venture pays a royalty of 4% each year in which the operation realizes a return on investment (ROI) greater than fifteen percent. For the purposes of these financial arrangements, the LOS Treaty defines ROI as being the ratio of the corporation's net proceeds (not adjusted for price) in a given year to its development costs in that year. If the operation does not realize a 15% ROI in a given year, the royalty is reduced to 2% for that year. The profit sharing payments are also calculated as determined by the time period. In the first period, 35% of attributable net proceeds from mining operations (as distinct from transport, processing, etc.) are paid on that portion of net proceeds representing between a zero and 10% ROI. Forty-two and one-half percent of attributable net proceeds are paid to the LOS Authority on that portion representing between 10% and 20% ROI and 50% of net proceeds are paid on any portion representing greater than a 20% ROI. During the second period, the percentages of profits are increased to 40%, 50%, and 70% for the low, medium, and high ROI's respectively.

For the purposes of the analysis in Chapter IV the downside case is assumed to include the treaty regulations in the above form. The upside case scenario considers only the regulations provided in the 1980 Deep Seabed Hard Mineral Resources Act.

2.2 Technology Transfer

The technology transfer provisions in the current treaty require that the technology being used by all mining corporations be made available to the Authority's mining operation, the enterprise, as well as to entities representing developing countries. When the rights to transfer the technology are owned by the mining corporation, the transfer is made possible through licensing or other arrangements (this would obviously result in a cash inflow to the corporation). If these rights to the technology are not owned by the mining corporation, the miner must assist the enterprise in gaining access to the technology or cease using that technology. Thus, the technology transfer provisions do not themselves cost the corporation anything in terms of cash expenditure. Rather, the cost is indirect and is a result of the forfeiture of proprietary rights to mining technology. This indirect cost is not quantifiable and is thus not considered further in this analysis. Competitors (in the form of developing country corporations) would be afforded easier entry to the industry through this transfer. However, without these corporations having a significant degree of market power (through market share), supply and price effects would be negligible if evident at all. One might also hypothesize, however, that this provision might encourage the development of mining technology which is most thorough, as opposed to being most efficient. That is, the

the corporation might be inclined to design mining equipment to gather as many nodules as possible, rather than only those which are most efficient to mine. This emphasis would also allow the fully-integrated corporation to take greater advantage of proprietary competitive advantages developed in other sectors of the operation.

2.3 Production Limits

Throughout the treaty negotiations, it has frequently appeared that some developing countries were "more interested in protecting nations that might be hurt by the competition from seabed minerals" than in obtaining large royalty payments. Canada was the country most concerned with this point. It was toward this end that an "interim period" was established. During this interim period (which lasts twenty-five years beginning with the first year of commercial operation) aggregate seabed mineral production limits are specified. The current treaty provides for a ceiling on the annual production of nickel from seabed nodules. The ceiling, equal to 60% of the annual growth in nickel consumption, is designed to protect land-based producers of all seabed minerals (manganese, copper, cobalt, and nickel) including Canada, Zambia, Zaire, and Chile. This provision obviously does not affect any individual operation, rather it limits the number and scope of aggregate permits granted by the authority. It is possible that advantageous price effects from only partially increased supply will accrue to the venture. In addition, the individual mining operation is limited to producing only that level of minerals specified in the operation's permit. Supplementary production authorization must be applied for in order to outstrip originally specified production levels. An absolute production limit of 46,500 tons of nickel per year is imposed on each permit (or "plan of work"). The production limitation is not expected to limit operations significantly.

2.4 Minesite Limitations

In order to deter overconcentration in a particular area by any single entity and to deter the formation of monopolistic interests, the LOS treaty specifies minesite limitations. These provisions limit concentration by any one entity to less than 30% of a circular area of 400,000 square kilometers measured from the center of any particular site. In addition, no single entity may receive permits totalling 2% or more of the total seabed area not reserved or otherwise withdrawn from consideration by the authority. Again, this provision does not affect the return from the pioneer venture in question. Such limitations do, however, constrain a corporation's aggregate profits from multiple minesites.

2.5 Uncertainties Remaining in the Legal Regime

Two major types of uncertainties are of great concern to the ocean mining consortia. These are the possibilities of authority-imposed delays and of strict environmental regulations.

The present treaty attempts to provide guidelines for the authority which will result in streamlined permitting and regulatory procedures. However, the untested nature of this international entity and its dependence upon international cooperation make the consortia understandably skeptical towards delay-proof operation. This concern becomes especially poignant in view of the regulatory lags present in many entirely U.S.-regulated industries. Thus, it is useful to consider the effects of preinvestment and preproduction delays.

In addition, the uncertain nature of the environmental restrictions cause a degree of anxiety. Strict environmental regulations could result in project delays and increased capital and operating costs. The magnitude of the possible delays and increased costs is obviously impossible to estimate. Thus, the downside scenario considers permitting and environmentally-related delays of two years at the preinvestment and preproduction junctures. Increased environmental control expenditures are considered in the "Capital Cost" and "Operating Costs" sections below.

3. Technological Status

Technological uncertainties still exist. Some relate to choices in technological systems yet to be made. For example, the locations of the processing plant and of the minesite itself, affect the distances transversed by the ore transports, and thus their number and size, as well as the size of the mineships storage capacity. This alternative is considered in appendix 3, Marine Transport.

Other problems are found in the mining, lifting, slurry transfer, and processing systems. Such problems could translate into project delays, decreased efficiencies, and/or increased costs. Optimistic developments in these technologies could result in increased efficiencies and decreased costs. (The base case assumes optimal development time).

3.1 Efficiency Effects

Efficiency effects caused by alterations of the operation's technological capabilities can take two broad forms: input tonnage effects and output tonnage effects. Input tonnage can be affected by altered efficiencies in the mine, lift, and slurry transport systems. The downside case scenario is assumed to decrease input tonnage by 10%, or 0.3 million dry short tons (MDST). The upside case scenario is assumed to increase input tonnage by 5%, or 0.15 MDST. In addition, altered input tonnage would obviously be accompanied by altered operating costs. Because the project is assumed to be operating at optimal capacity, costs do not vary directly with output. Thus it is assumed that a 5% increase in output is accompanied by a 5% increase in operating costs whereas a 10% decrease in output is accompanied by only a 5% decrease in costs. Further cost effects are considered under cost effects sections, 4 and 5.

Output tonnage can be affected by altered processing efficiencies, input tonnage, and ore grade. A 10% decrease in any of these factors will result in the same net effect -- a 10% decrease in output tonnage. An increase in any of these factors will also have the same net effect -- a commensurate increase in output tonnage. Efficiency effects are considered in the downside case scenario by assuming a 10% decrease in output tonnage. This effect could be a result of input and/or output effects. A 5% increased output tonnage is included in the upside case scenario to account for the possibility of increased input and/or output efficiencies.

3.2 Project Delays

Problems in the development and implementation of deep ocean mining technology may result in project delays. These delays are most likely to occur during the preproduction and investment phases (which include a testing period) or shortly thereafter. A one-year intrainvestment period delay is considered in the downside case scenario to simulate a technologically-related delay. Two year preproduction and preinvestment delays are already included in the worst case scenario to consider the consequences of international legal uncertainty (see Chapter IV B 3 b). It is assumed that these delays might result from both regulatory and technological causes. In actuality, the delays may overlap or occur concurrently. For the purposes of this analysis, these delays are considered sequentially to illustrate the downside case scenario and the individual delay effects separately.

3.3 Cost Effects

The technological status and capability of a mining venture can also result in cost effects. Technological problems or inefficiencies frequently translate into increased operating or capital costs. These costs are considered in the following sections.

4. Capital Costs

Capital cost estimates may suffer from two types of inaccuracies. These are absolute estimating errors and misestimation of real growth. Absolute estimating errors may result from inaccurate operating assumptions, unexpected technological problems, altered technological choices, unexpected environmental restrictions, as well as various other possible causes. Development cost estimates obtained in eight studies of deep sea mining are summarized in Table 7-2. As evidenced by Table 7-2 and by the various possible eventualities previously discussed, the absolute value of the capital costs may vary considerably. In order to consider the effects of misestimation, the downside case scenario assumes 25% higher capital costs and the upside case scenario assumes 25% decreased capital costs.

The base set of assumptions assumes no real growth in capital costs. As an alternative to this scenario, a 1% annual real growth rate for capital costs is considered in the downside case scenario.

5. Operating Costs

Similarly, actual operating costs may also differ from estimates in either absolute amount or in the real growth rate. In order to consider these effects, operating costs are treated similarly to capital costs. The downside case assumes 25% increased operating costs which exhibit a 1% real growth rate. The upside case assumes 25% decreased operating costs.

TABLE 7-2

SUMMARY OF RECENTLY PUBLISHED ESTIMATES FOR DEVELOPMENT COSTS OF ONE INTEGRATED SEABED MINING PROJECT

Author and date of publication	No. of metals	Capacity of operation/year	Items of Cost included	Unit of currency	Cost estimates
Wright (1976)	3	3M* dry tons	Exploration + R&D + Capital cost + Working capital	1975 $US	$500m* - low $640m - med $750m - high
Shaw (1977)	4	3M dry tons	Exploration + R&D + Capital cost + Working capital	1976 $US	$730m
Dames & Moore - EIC Corp (1977)	3	3M dry met. tons	Exploration + R&D + Capital cost in mining and processing	1976 $US	$490m - one ship mining $520m - two ship mining
	4	1M dry met. tons	"	1976 $US	$450m
Nyhart (1978)	3	3M dry short tons	Prospecting + Exploration + R&D + Capital cost	1976 $US	$560m
Tinsley (1978)	3	1.5M tons	Exploration + R&D + Capital cost + Working capital	1977 $US	$625m - Kennecott
	4	0.95M met. tons	"	1977 $US	$340m - OMA
	4	3M dry met. tons	Capital cost	1977 $US	$450m - OMI

*M = 1 million

TABLE 7-2

SUMMARY OF RECENTLY PUBLISHED ESTIMATES FOR DEVELOPMENT COSTS OF ONE INTEGRATED SEABED MINING PROJECT. (Cont'd.)

Author and date of publication	No. of metals	Capacity of operation/year	Items of Cost included	Unit of currency	Cost estimates
Tinsley (1978) (cont.)	3	1.5 met. tons	Exploration + R&D + Capital cost + Working capital	1977 $US	$400m - OMINCO
	3	2M* dry tons	Capital cost	1977 $US	$250m - AFERNOD
Diederich (1979)	3	3M dry short tons	Prospecting + Exploration + R&D + Capital cost	1976 $US	$970m
Arthur D. Little (1979)	3+ Molyb-denbum	3M short tons	Capital cost	1978 $US	$645m - Ammonia leach processing
	4+ Molyb-denum	3M short tons	Capital cost	1978 $US	$900m - Ammonia leach processing
	4+ Molyb-denum	3M short tons	Capital cost	1978 $US	$775m - Pyro-metallugical processing
Lenoble (1980)	3	3M dry met. tons	R&D + Capital cost + working capital	1979 $US	$1,250m
	4	2M dry met. tons	"	1979 $US	$1,325m

*M = 1 million

TABLE 7-2

SUMMARY OF RECENTLY PUBLISHED ESTIMATES FOR DEVELOPMENT COSTS OF ONE INTEGRATED SEABED MINING PROJECT

(Cont'd.)

Sources

Wright (1976):	Rebecca L. Wright, Ocean Mining: An Economic Evaluation, (United States Department of the Interior, Ocean Mining Administration, May 1976), table 6, p. 11.
Shaw (1977):	K.D. Shaw, Ocean Mining Costs and Revenue, Report No. 16 presented to Seminar under the auspices of the European Economic Community for the benefit of the ACP Experts to the United Nations Conference on the Law of the Sea, on the Exploitation of the Deep-Seabed, Brussels, 22-25 February 1977, table. 1.
Dames & Moore - EIC Corp (1977):	Dames and Moore and EIC Corporation, Description of Manganese Nodule Processing Activities for Environmental Studies, volume I, Processing Systems Summary (United States Department of Commerce, National Oceanic and Atmospheric Administration, 1977), table 2.3, pp. 2-8.
Nyhart (1978):	J.D. Nyhart et al., A Cost Model of Deep Ocean Mining and Associated Regulatory Issues (Massachusetts Institute of Technology, Cambridge, Mass., 1978), MIT Sea Grant Report MITSG 78-4, prepared for the United States Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Minerals, table ES-1, p. ES-3 and table V-1, p. 82.
Tinsley (1978):	C. Richard Tinsley, Capital Costs for Individual Manganese Nodule Mining Consortia, presented to McGill University seminar, "Deep sea bed mining of manganese nodules - a commercial approach to the challenges", Montreal, 16 March 1978, pp. 7, 12, 17, 20 and 23.
Diederich (1979):	Franz Diederich, Wolfgang Müller and Wolfgang Schneider, Analysis of the MIT Study on Deep Ocean Mining - Critical Remarks on Technologies and Cost Estimates: Summary (Research Institute for International Techno-Economic Co-operation, Technical University, Aachen and Battelle-Institute e. V., Frankfurt, 1979), table 1.1, p. 10.

TABLE 7-2

SUMMARY OF RECENTLY PUBLISHED ESTIMATES FOR DEVELOPMENT COSTS OF ONE INTEGRATED SEABED MINING PROJECT

(Cont'd.)

Arthur D. Little (1979):	Arthur D. Little, Inc., Technological and Economic Asssessment of Manganese Nodule Mining and Processing, revised ed. (Cambridge, Mass., 1979), prepared for the United States Department of the Interior, Office of Minerals Policy and Research Analysis, table 1, p. 5 and table 12, p. 43., OMPRA 14-01-0001-21140.
Lenoble (1980):	J.-P. Lenoble, Polymetallic Nodules Resources and Reserves in North Pacific from the Data Collected by AFERNOD, presented at Oceanology International 80, Brighton, February 1980, table 5.

Source: Excerpted from UN Document: Potential Financial Implications for States Parties to the Future Convention on the Law of the Sea, A/CONF. 62/L.65 February, 1981.

6. Depletion Allowance

At present, the treatment of depletion by the U.S. Internal Revenue Service is uncertain. It appears that most likely the minesites will be considered as foreign mineral deposits. In addition, the permitting procedure will probably confer an "economic interest" to the minerals (for tax purposes). Thus, the base set of assumptions assumes a foreign deposit percentage depletion allowance of 14% for all minerals. The downside case scenario would result in a disallowed "economic interest", and thus no percentage depletion. The upside case would consider the deposit as domestic and enable the venture to claim percentage depletion of 22% for nickel and cobalt and 15% for copper.

Appendix 8. SUMMARY OF INPUT VARIABLES AND OUTPUT

This appendix comprises three parts:

1. The M.I.T. model's computer program printout giving a summary of the capital and operating costs as calculated in the text and appendices, a summary of other significant inputs, a summary of the resulting financial analysis and a cash flow statement for each life of the hypothetical project. Some annotation is provided. The printout is provided both for the set of assumptions discussed in the text and appendices and for the slightly different costs of an earlier set of assumptions upon which the analysis in chapter IV is based. (See chapter IV, note 3 .)

2. The full output table forming the data base for the analysis in chapter IV.

3. An identification of the major input variables, in addition to those appearing in the printout, the values of which can be changed by the user.

1. PRINT OUT OF MODEL ANALYSIS BASED ON COST ESTIMATES PROVIDED IN CHAPTER II AND AS USED IN CHAPTER IV

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($ 1 X 1MILLION)

(AT VARIOUS DISCOUNT RATES)

DISCOUNT RATES	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00
	34.83	67.08	115.17	186.34	291.12	445.01	670.86	1002.58	1490.68

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

PREPARATORY COSTS ($MM)

CATEGORY	CAPITALIZED	EXPENSED	TOTAL
PROSPECTING	5.00	0.0	5.00
EXPLORATION	25.00	0.0	25.00
R&D	0.0	136.00	136.00
PROJECT FEASIBILITY	0.0	0.0	0.0
PERMITTING	0.0	0.0	0.0
UP-FRONT G&A	0.0	6.00	6.00

BONUS	0.0			0.0
TOTALS		30.00		142.00	

CONTINUING PREPARATION COSTS

CATEGORY	CAPITALIZED ($MM)		EXPENSED ($MM/YR)	
CONTINUING EXPLORATION	0.0		4.00	
CONTINUING R&D	0.0		2.00	
TOTALS		0.0		6.00

CAPITAL COST SUMMARY

MINING SECTOR		
HANDLING & STORAGE	34.10	
PUMPING SYSTEMS	24.80	
DREDGE PIPELINES	39.20	
COLLECTORS	7.00	
ORE HANDLING	20.40	
MINESHIPS	180.74	
TOTAL MINING SECTOR COSTS		306.24
TRANSPORT SECTOR		
ORE SHIPS	200.88	
LOGISTICS SUPPORT	0.0	
SPARE PARTS	0.0	
TOTAL TRANSPORT COSTS		200.88
MARINE TERMINAL SECTOR		
PIER	12.44	
ORE DISCHARGE & STORAGE	8.24	
SITE IMPROVEMENTS	0.87	
BUILDINGS	1.32	
TOTAL MARINE TERMINAL COSTS		22.87
ONSHORE TRANSPORTATION SECTOR		
NODULE PIPELINE	10.89	
WASTE PIPELINE	22.40	
RAIL LINES	1.00	
ACCESS ROADS	1.00	
LAND	1.36	
TOTAL ONSHORE TRANSPORT COSTS		36.65

1DEEP OCEAN MINING STUDY
RUN NUMBER

CAPITAL COST SUMMARY CONTINUED

PROCESSING SECTOR		
PLANT EQUIPMENT	291.20	
UTILITIES	105.70	
BUILDINGS	40.10	
SITE PREPARATION	11.10	
LAND	1.00	
TOTAL PROCESSING COSTS		449.10
WASTE DISPOSAL SECTOR		
EQUIPMENT	0.50	

BUILDINGS	0.0		
SITE IMPROVEMENTS	11.53		
LAND	3.25		
TOTAL WASTE DISPOSAL COSTS		15.28	
MARINE SUPPORT SECTOR			
CREW/SUPPLY BOAT	1.80		
CREW/SUPPLY TERMINAL	0.0		
RESEARCH VESSEL	0.0		
CREW TRAINING	0.0		
TOTAL MARINE SUPPORT COSTS		1.80	
GENERAL & ADMINISTRATIVE SECTOR			
HEADQUARTERS	22.00		
REGULATORY COMPLIANCE	0.0		
TESTING COSTS	66.20		
TOTAL G&A COSTS		88.20	
TOTAL CAPITAL COST			1121.02

OPERATING COST SUMMARY

MINING SECTOR		
LABOR	19.88	
M&R	30.74	
INSURANCE	5.60	
FUEL	9.36	
TOTAL		65.58
ORE SHIPS SECTOR		
SHIP LABOR	7.76	
SHIP M&R	2.04	
SHIP INSURANCE	2.40	
SHIP FUEL & OIL	8.96	
SHIP STORES/SUBSIST.	0.0	
SHIP G&A	0.0	
PORT CHARGES	0.52	
HELICOPTER (LEASE)	0.0	
LOGISTICS SUPPORT	0.52	
TOTAL		22.20

1DEEP OCEAN MINING STUDY
RUN NUMBER

OPERATING COST SUMMARY CONTINUED

MARINE TERMINAL SECTOR		
LABOR	0.95	
M&R	1.23	
INSURANCE	0.46	
UTILITIES	0.25	
RENT	0.30	
TOTAL		3.19
ONSHORE TRANSPORTATION		
NODULE PIPELINE	3.20	
WASTE PIPELINE	4.48	
RAIL LINES	0.0	
ACCESS ROADS	0.0	
TOTAL		7.68
PROCESSING SECTOR		
MATERIALS & SUPPLIES	4.00	

UTILITIES & FUEL	47.50		
LABOR	16.70		
FIXED CHARGES	31.40		
TOTAL		99.60	
WASTE DISPOSAL SECTOR			
MATERIALS & SUPPLIES	0.30		
LABOR	0.30		
NEW PONDS	3.30		
FIXED CHARGES	0.0		
TOTAL		3.90	
MARINE SUPPORT SECTION			
CREW/SUPPLY BOAT	0.80		
CREW/SUPPLY TERMINAL	0.38		
RESEARCH VESSEL RENT	3.50		
CREW TRAINING	0.20		
TOTAL		4.88	
GENERAL & ADMINISTRATIVE SECTOR			
HEADQUARTERS	4.00		
REGULATORY COMPLIANCE	0.0		
TOTAL		4.00	
TOTAL OPERATING COST			211.03

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1
0VALUES OF INPUT PARAMETERS:

FINANCIAL PARAMETERS

TIME FACTORS: (YEARS)

PROJECT STARTUP :	1
EXPLORATION PERIOD :	7
R&D PERIOD :	16
INVESTMENT PERIOD :	6
OPERATING PERIOD :	25
TOTAL DELAYS :	0
PROJECT LIFE :	46

TECHNOLOGICAL FACTORS:

NOMINAL ORE PRODUCTION/YR (MDST) : 3.00

CAPITAL INVESTMENT ($MILLION) : 1121.02
OPERATING EXPENSE/YR($MILLION) : 211.03
STARTUP EFFICIENCIES:
PRODUCTION : 25.00%
COST : 50.00%
RECOVERY EFFICIENCIES:
NICKEL : 94.83
COPPER : 91.74
COBALT : 57.33

ECONOMIC FACTORS:

AVERAGE ANNUAL REAL GROWTH:
CAPITAL EQUIPMENT : 0.0%
COMMODITY VALUES : 0.0%
OPERATING EXPENSES : 0.0%
DISCOUNT RATE : 0.0%

	COMPOSITION:	COMMODITY VALUES:
NI	1.29	$ 3.75
CU	1.09	$ 1.25
CO	0.25	$ 5.63

FINANCIAL FACTORS:

DEBT FUNDING : 50.00%
INTEREST RATE : 5.00%

POLICY FACTORS:

TAX RATE : 46.00%
INVESTMENT CREDIT : 10.00%
SOCIAL DISCOUNT RATE: 10.00%

LDFTC(1 IF FTC) :0 LDEX(1 IF UNLIMIT EXPLOR DEDUCT) :0 LDADR(1 IF ADR MINE&TRAN) :0
LDITC(1 IF P,M;2 IF P,M,T) :2 LDORG1(1=CORP;2=PART;3=STOCK) :1 LDORG2(1=P,M,T;2=P,M;3=P) :1
LD(1 IF NO TAX) :0 PR(FOR. CORP INTEREST RATE) :0.0 MORTZ(0 IF EXPENSE EXP) : 1
DEBT FUNDING:50.00%PERIOD: 10 DEPLETION ALLOWANCE : 14.00%,14.00%,14.00%,

OUTPUT SUMMARY ($MILLION)

TOT TAX REVENUE : 1197.92 FOREIGN CORP DIVIDEND : 0.0
PROJECT IROR : 9.76% TOTAL CASH FLOW 2079.40 DISCOUNT TAX: 37.85
TOT UN TAX : 0.0 SPB IN 13.6 YEARS ; ITC : 93.68UTR: 0.37
DISCOUNT INCOME: 148.10 DTR:0.053BEFORE TAX IROR:0.208CTR:0.532

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

0 YEAR	1	2	3	4	5	6	7	8	9	10
0COMMODITY SALES(LBS X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0COMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0
--- OPERATING STATEMENTS ---

0 YEAR	1	2	3	4	5	6	7	8	9	10
0GROSS REVENUES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST OF GOODS SOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MARKET & GENL EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R&D/P&E EXPENSE	3.04	3.04	3.04	3.04	3.04	3.04	3.04	8.28	8.28	8.28
GROSS PROFIT	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
DEPRECIATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE INTEREST&TAX	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	8.28	-8.28
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FOREIGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28

0
--- CASH FLOW SUMMARIES ---

	1	2	3	4	5	6	7	8	9	10
NET INCOME	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
DEPRECIATION EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	1.67	1.67	1.67	3.57	3.57	3.57	3.57	3.57	3.57	3.57
CASH FLOW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0PLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	-1.58	-1.58	-1.58	-1.58	-1.58	-1.58	-1.58	-4.31	-4.31	-4.31

CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	11	12	13	14	15	16	17	18	19	20
COMMODITY SALES(LBS X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

--- OPERATING STATEMENTS ---

0 YEAR	11	12	13	14	15	16	17	18	19	20
0GROSS REVENUES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST OF GOODS SOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MARKET & GENL EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R&D/P&E EXPENSE	8.28	8.28	26.09	17.75	17.75	17.75	6.00	6.00	6.00	6.00
GROSS PROFIT	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.00	-6.00	-6.00	-6.00
DEPRECIATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE INTEREST&TAX	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.00	-6.00	-6.00	-6.00
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.39	1.89	6.09	12.45
ROYALTY PAYMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.39	-7.89	-12.09	-18.45
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.39	-7.89	-12.09	-18.45
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.39	-7.89	-12.09	-18.45

--- CASH FLOW SUMMARIES ---

0

	11	12	13	14	15	16	17	18	19	20
NET INCOME	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.39	-7.89	-12.09	-18.45
DEPRECIATION EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	0.0	0.0	0.0	0.0	0.0	0.0	7.79	30.04	83.91	127.23
CASH FLOW	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-14.18	-37.93	-95.99	-145.68
0PLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00	1.00
EARNING FROM MINING	-4.31	-4.31	-13.59	-9.25	-9.25	-9.25	-6.11	-6.52	-7.66	-9.40
CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

0 YEAR	21	22	23	24	25	26	27	28	29	30

0COMMODITY SALES(LBS X 1MILLION):

NICKEL	0.0	18.35	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	0.0	15.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	0.0	2.15	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60
OCOMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	68.81	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	0.0	18.75	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	0.0	12.10	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42

--- OPERATING STATEMENTS ---

YEAR	21	22	23	24	25	26	27	28	29	30
OGROSS REVENUES	0.0	106.21	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	0.0	103.86	207.73	211.03	211.03	211.03	211.03	211.03	211.03	211.03
MARKET & GENL EXPENSE	0.0	2.37	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	-6.00	-6.03	201.62	198.32	198.32	198.32	198.32	198.32	198.32	198.32
DEPRECIATION	0.0	93.43	93.43	93.43	93.43	93.43	93.43	93.43	93.43	93.61
INCOME BEFORE INTEREST&TAX	-6.00	-99.46	108.19	104.89	104.89	104.89	104.89	104.89	104.89	104.71
INTEREST EXPENSE	21.21	28.03	28.03	25.80	23.46	21.00	18.42	15.71	12.87	9.88
ROYALTY PAYMENT	0.0	0.80	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-27.21	-128.28	76.98	75.91	78.24	80.70	83.28	85.99	88.83	91.64
DEPLETION ALLOWANCE	0.0	1.20	13.52	13.16	13.57	14.01	14.46	14.93	15.43	15.90
TAX LOSS CARRY-FORWARD	0.0	0.0	63.45	62.75	64.67	28.39	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-27.21	-129.48	0.0	0.0	0.0	38.30	68.82	71.06	73.40	75.74
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	15.86	28.50	29.42	13.57	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	1.73	3.14	3.24	20.18	34.82
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-27.21	-129.48	0.0	0.0	0.0	36.57	65.68	67.81	53.22	40.92

--- CASH FLOW SUMMARIES ---

NET INCOME	-27.21	-129.48	0.0	0.0	0.0	36.57	65.68	67.81	53.22	40.92
DEPRECIATION EXPENSE	0.0	93.43	93.43	93.43	93.43	93.43	93.43	93.43	93.43	93.61
DEPLETION ALLOWANCE	0.0	1.20	13.52	13.16	13.57	14.01	14.46	14.93	15.43	15.90
TAX LOSS CARRY-FORWARD	0.0	0.0	63.45	62.75	64.67	28.39	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	175.27	178.84	87.15	48.15	49.13	51.59	54.17	56.88	59.72	62.71
CASH FLOW	-202.48	-213.69	83.26	121.19	122.55	120.81	119.41	119.30	102.36	87.73
OPLANT DEBT/EQUITY RATIO	1.00	1.00	0.85	0.72	0.60	0.49	0.39	0.30	0.21	0.14
EARNING FROM MINING	-11.79	-48.96	13.52	13.16	13.57	14.01	14.46	14.93	15.43	15.90
CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.16	0.42	0.67	2.07	4.27
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	31	32	33	34	35	36	37	38	39	40
OCOMMODITY SALES(LBS X 1MILLION):										
NICKEL	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60
OCOMMODITY REVENUES($ X 1MILLION):										
NICKEL	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42

--- OPERATING STATEMENTS ---

YEAR	31	32	33	34	35	36	37	38	39	40
GROSS REVENUES	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	211.03	211.03	211.03	211.03	211.03	211.03	211.03	211.03	211.03	211.03
MARKET & GENL EXPENSE	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	198.32	198.32	198.32	198.32	198.32	198.32	198.32	198.32	198.32	198.32
DEPRECIATION	93.61	19.51	19.51	19.51	19.51	19.51	19.51	14.79	14.79	14.79
INCOME BEFORE INTEREST&TAX	104.71	178.81	178.81	178.81	178.81	178.81	178.81	183.53	183.53	183.53
INTEREST EXPENSE	6.75	3.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	94.77	172.17	175.63	175.63	175.63	175.63	175.63	180.35	180.35	180.35
DEPLETION ALLOWANCE	16.44	21.33	21.28	21.28	21.28	21.28	21.28	21.69	21.69	21.69
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	78.33	150.84	154.35	154.35	154.35	154.35	154.35	158.66	158.66	158.66
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	36.01	69.37	70.98	70.98	70.98	70.98	70.98	72.96	72.96	72.96
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	42.32	81.47	83.37	83.37	83.37	83.37	83.37	85.69	85.69	85.69

--- CASH FLOW SUMMARIES ---

	31	32	33	34	35	36	37	38	39	40
NET INCOME	42.32	81.47	83.37	83.37	83.37	83.37	83.37	85.69	85.69	85.69
DEPRECIATION EXPENSE	93.61	19.51	19.51	19.51	19.51	19.51	19.51	14.79	14.79	14.79
DEPLETION ALLOWANCE	16.44	21.33	21.28	21.28	21.28	21.28	21.28	21.69	21.69	21.69
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	65.84	69.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CASH FLOW	86.53	53.19	124.15	124.15	124.15	124.15	124.15	122.17	122.17	122.17
PLANT DEBT/EQUITY RATIO	0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	16.44	42.50	43.70	43.70	43.70	43.70	43.70	46.45	46.45	46.45
CUMULATIVE DISCOUNTED TAX	6.33	9.94	13.31	16.36	19.14	21.67	23.96	26.11	28.06	29.83
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

YEAR	41	42	43	44	45	46
COMMODITY SALES(LBS X 1MILLION):						
NICKEL	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	8.60	8.60	8.60	8.60	8.60	8.60
COMMODITY REVENUES($ X 1MILLION):						
NICKEL	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	48.42	48.42	48.42	48.42	48.42	48.42

--- OPERATING STATEMENTS ---

YEAR	41	42	43	44	45	46
GROSS REVENUES	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	211.03	211.03	211.03	211.03	211.03	207.73
MARKET & GENL EXPENSE	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	198.32	198.32	198.32	198.32	198.32	201.62
DEPRECIATION	14.79	6.89	6.89	6.89	6.89	6.89

INCOME BEFORE INTEREST&TAX	183.53	191.43	191.43	191.43	191.43	194.73
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	180.35	188.25	188.25	188.25	188.25	191.55
DEPLETION ALLOWANCE	21.69	22.43	22.43	22.43	22.43	22.75
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	158.66	165.82	165.82	165.82	165.82	168.80
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0
TAX	72.96	76.26	76.26	76.26	76.26	77.63
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	85.69	89.56	89.56	89.56	89.56	91.17

--- CASH FLOW SUMMARIES ---

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NET INCOME	85.69	89.56	89.56	89.56	89.56	91.17
DEPRECIATION EXPENSE	14.79	6.89	6.89	6.89	6.89	6.89
DEPLETION ALLOWANCE	21.69	22.43	22.43	22.43	22.43	22.75
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	0.0	0.0	0.0	0.0	0.0	-163.13
CASH FLOW	122.17	118.88	118.88	118.88	118.88	283.94
OPLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	46.45	51.31	51.31	51.31	51.31	53.43
CUMULATIVE DISCOUNTED TAX	31.44	32.98	34.37	35.63	36.79	37.85
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY

RUN NUMBER 1 - 1

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($ 1 X 1MILLION)

(AT VARIOUS DISCOUNT RATES)

DISCOUNT RATES	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00
	-3.02	14.86	42.78	85.46	149.83	246.07	389.22	601.62	916.58

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DEEP OCEAN MINING STUDY

SUMMARY

PROJECT	RUN	STARTUP	LIFE (YRS)	TAXR ($X 1MILLION)	SDR	IROR	PAYBACK	COMMENTS
O 1	1	1	46	$ 0.0	(10.00%)	9.76%	13.6 YRS	

PRINT OUT OF MODEL ANALYSIS WITH COSTS USED IN ANALYSIS IN CHAPTER IV

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($ 1 X 1MILLION)

(AT VARIOUS DISCOUNT RATES)

DISCOUNT RATES	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00
	25.58	55.78	101.44	169.75	271.27	421.62	643.93	972.71	1459.62

DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

PREPARATORY COSTS ($MM)

CATEGORY	CAPITALIZED	EXPENSED	TOTAL
PROSPECTING	5.00	0.0	5.00
EXPLORATION	25.00	0.0	25.00
R&D	0.0	136.00	136.00
PROJECT FEASIBILITY	0.0	0.0	0.0
PERMITTING	0.0	0.0	0.0
UP-FRONT G&A	0.0	6.00	6.00

BONUS	0.0			0.0
TOTALS		30.00	142.00	

CONTINUING PREPARATION COSTS

CATEGORY	CAPITALIZED ($MM)		EXPENSED ($MM/YR)	
CONTINUING EXPLORATION	0.0		4.00	
CONTINUING R&D	0.0		2.00	
TOTALS		0.0		6.00

CAPITAL COST SUMMARY

MINING SECTOR		
HANDLING & STORAGE	34.10	
PUMPING SYSTEMS	24.80	
DREDGE PIPELINES	39.20	
COLLECTORS	7.00	
ORE HANDLING	20.40	
MINESHIPS	197.12	
TOTAL MINING SECTOR COSTS		322.62
TRANSPORT SECTOR		
ORE SHIPS	195.60	
LOGISTICS SUPPORT	0.38	
SPARE PARTS	3.41	
TOTAL TRANSPORT COSTS		199.39
MARINE TERMINAL SECTOR		
PIER	16.43	
ORE DISCHARGE & STORAGE	11.29	
SITE IMPROVEMENTS	0.87	
BUILDINGS	1.32	
TOTAL MARINE TERMINAL COSTS		29.91
ONSHORE TRANSPORTATION SECTOR		
NODULE PIPELINE	10.88	
WASTE PIPELINE	5.94	
RAIL LINES	2.38	
ACCESS ROADS	1.54	
LAND	3.69	
TOTAL ONSHORE TRANSPORT COSTS		24.43

1DEEP OCEAN MINING STUDY
RUN NUMBER

CAPITAL COST SUMMARY CONTINUED

PROCESSING SECTOR		
PLANT EQUIPMENT	297.90	
UTILITIES	92.20	
BUILDINGS	52.50	
SITE PREPARATION	14.60	
LAND	1.00	
TOTAL PROCESSING COSTS		458.20
WASTE DISPOSAL SECTOR		
EQUIPMENT	0.0	

BUILDINGS	0.24		
SITE IMPROVEMENTS	16.63		
LAND	0.0		
TOTAL WASTE DISPOSAL COSTS		16.87	
MARINE SUPPORT SECTOR			
CREW/SUPPLY BOAT	1.32		
CREW/SUPPLY TERMINAL	0.0		
RESEARCH VESSEL	0.0		
CREW TRAINING	0.0		
TOTAL MARINE SUPPORT COSTS		1.32	
GENERAL & ADMINISTRATIVE SECTOR			
HEADQUARTERS	22.00		
REGULATORY COMPLIANCE	0.0		
TESTING COSTS	66.20		
TOTAL G&A COSTS		88.20	
TOTAL CAPITAL COST			1140.94

OPERATING COST SUMMARY

MINING SECTOR		
LABOR	20.16	
M&R	32.62	
INSURANCE	3.70	
FUEL	8.40	
TOTAL		64.88
ORE SHIPS SECTOR		
SHIP LABOR	7.76	
SHIP M&R	2.00	
SHIP INSURANCE	2.31	
SHIP FUEL & OIL	7.90	
SHIP STORES/SUBSIST.	0.0	
SHIP G&A	0.45	
PORT CHARGES	1.00	
HELICOPTER (LEASE)	0.60	
LOGISTICS SUPPORT	0.03	
TOTAL		22.05

1DEEP OCEAN MINING STUDY
RUN NUMBER

OPERATING COST SUMMARY CONTINUED

MARINE TERMINAL SECTOR		
LABOR	0.35	
M&R	1.73	
INSURANCE	0.30	
UTILITIES	0.25	
RENT	0.60	
TOTAL		3.23
ONSHORE TRANSPORTATION		
NODULE PIPELINE	8.97	
WASTE PIPELINE	2.46	
RAIL LINES	0.20	
ACCESS ROADS	0.03	
TOTAL		11.66
PROCESSING SECTOR		
MATERIALS & SUPPLIES	4.00	

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ABOUT     DATA      A              VM/SP CONVERSATIONAL MONITOR SYSTEM                    PAGE 027

     UTILITIES & FUEL                 47.50
     LABOR                            16.50
     FIXED CHARGES                    32.10
        TOTAL                                  100.10
   WASTE DISPOSAL SECTOR
     MATERIALS & SUPPLIES              0.0
     LABOR                             0.0
     NEW PONDS                         5.47
     FIXED CHARGES                     0.0
        TOTAL                                    5.47
   MARINE SUPPORT SECTION
     CREW/SUPPLY BOAT                  0.80
     CREW/SUPPLY TERMINAL              0.38
     RESEARCH VESSEL RENT              4.23
     CREW TRAINING                     0.20
        TOTAL                                    5.61
   GENERAL & ADMINISTRATIVE SECTOR
     HEADQUARTERS                      4.00
     REGULATORY COMPLIANCE             0.0
        TOTAL                                    4.00
           TOTAL OPERATING COST                           217.00

1DEFP OCEAN MINING STUDY
 RUN NUMBER  1 -  1
0VALUES OF INPUT PARAMETERS:

 FINANCIAL PARAMETERS

     TIME FACTORS:            TECHNOLOGICAL FACTORS:                                  ECONOMIC FACTORS:
       (YEARS)

  PROJECT STARTUP     :   1   NOMINAL ORE PRODUCTION/YR (MDST) :    3.00    AVERAGE ANNUAL REAL GROWTH:
  EXPLORATION PERIOD  :   7                                                     CAPITAL EQUIPMENT   : 0.0%
  R&D PERIOD          :  16                                                     COMMODITY VALUES : 0.0%
  INVESTMENT PERIOD   :   6   CAPITAL INVESTMENT  ($MILLION)    : 1140.94       OPERATING EXPENSES   : 0.0%
  OPERATING PERIOD    :  25   OPERATING EXPENSE/YR($MILLION)    :  217.00       DISCOUNT RATE        : 0.0%
  TOTAL DELAYS        :   0   STARTUP EFFICIENCIES:
  PROJECT LIFE        :  46                 PRODUCTION          :   25.00%
                                            COST                :   50.00%
                              RECOVERY EFFICIENCIES:                            COMPOSITION:   COMMODITY VALUES:
                                           NICKEL     :   94.83          NI         1.29          $ 3.75
                                           COPPER     :   91.74          CU         1.09          $ 1.25
                                           COBALT     :   57.33          CO         0.25          $ 5.63

                 FINANCIAL FACTORS:          POLICY FACTORS:

        DEBT FUNDING            : 50.00%        TAX RATE              :  46.00%
        INTEREST RATE           :  5.00%        INVESTMENT CREDIT     :  10.00%
                                                SOCIAL DISCOUNT RATE:    10.00%
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LDFTC(1 IF FTC)            :0  LDEX(1 IF UNLIMIT EXPLOR DEDUCT)    :0  LDADR(1 IF ADR MINE&TRAN) :0
LDITC(1 IF P,M;2 IF P,M,T) :2  LDORG1(1=CORP;2=PART;3=STOCK)       :1  LDORG2(1=P,M,T;2=P,M;3=P) :1
LD(1 IF NO TAX)            :0       PR(FOR. CORP INTEREST RATE)    :0.0  MORTZ(O IF EXPENSE EXP) : 1
        DEBT FUNDING:50.00%PERIOD: 10                  DEPLETION ALLOWANCE :  14.00%,14.00%,14.00%,
                                          OUTPUT SUMMARY  ($MILLION)

                     TOT TAX REVENUE :  1172.11         FOREIGN CORP DIVIDEND :       0.0
                     PROJECT IROR    :    9.21% TOTAL CASH FLOW       2166.28 DISCOUNT TAX:        38.46
                     TOT UN TAX      :    0.0  SPB IN 14.7 YEARS ; ITC :   34.35UTR: 0.35
                     DISCOUNT INCOME:     137.07 DTR:0.053BEFORE TAX IROR:0.208CTR:0.558
1DEEP OCEAN MINING STUDY
 RUN NUMBER  1 -  1
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--- SALES ANALYSIS ---

O YEAR	1	2	3	4	5	6	7	8	9	10
OCOMMODITY SALES(LBS X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCOMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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--- OPERATING STATEMENTS ---

O YEAR	1	2	3	4	5	6	7	8	9	10
OGROSS REVENUES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST OF GOODS SOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.C	0.0	0.0
MARKET & GENL EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R&D/P&E EXPENSE	3.04	3.04	3.04	3.04	3.04	3.04	3.04	8.28	8.28	8.28
GROSS PROFIT	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
DEPRECIATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE INTEREST&TAX	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28

--- CASH FLOW SUMMARIES ---

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	1	2	3	4	5	6	7	8	9	10
NET INCOME	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-3.04	-8.28	-8.28	-8.28
DEPRECIATION EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	1.67	1.67	1.67	3.57	3.57	3.57	3.57	3.57	3.57	3.57
CASH FLOW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OPLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	-1.58	-1.58	-1.58	-1.58	-1.58	-1.58	-1.58	-4.31	-4.31	-4.31

CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

0 YEAR	11	12	13	14	15	16	17	18	19	20
0COMMODITY SALES(LBS X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0COMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPPER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COBALT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0 --- OPERATING STATEMENTS ---

0 YEAR	11	12	13	14	15	16	17	18	19	20
0GROSS REVENUES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST OF GOODS SOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MARKET & GENL EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R&D/P&E EXPENSE	8.28	8.28	26.09	17.75	17.75	17.75	6.00	6.00	6.00	6.00
GROSS PROFIT	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.00	-6.00	-6.00	-6.00
DEPRECIATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE INTEREST&TAX	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.00	-6.00	-6.00	-6.00
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.40	1.93	6.20	12.67
ROYALTY PAYMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.40	-7.93	-12.20	-18.67
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.40	-7.93	-12.20	-18.67
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.40	-7.93	-12.20	-18.67

0 --- CASH FLOW SUMMARIES ---

NET INCOME	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-6.40	-7.93	-12.20	-18.67
DEPRECIATION EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEPLETION ALLOWANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	0.0	0.0	0.0	0.0	0.0	0.0	7.93	30.58	85.40	129.49
CASH FLOW	-8.28	-8.28	-26.09	-17.75	-17.75	-17.75	-14.33	-38.50	-97.59	-148.16
0PLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00	1.00
EARNING FROM MINING	-4.31	-4.31	-13.59	-9.25	-9.25	-9.25	-6.11	-6.54	-7.75	-9.58
CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

0 YEAR	21	22	23	24	25	26	27	28	29	30

0COMMODITY SALES(LBS X 1MILLION):

NICKEL	0.0	18.35	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	0.0	15.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	0.0	2.15	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60
OCOMMODITY REVENUES($ X 1MILLION):										
NICKEL	0.0	68.81	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	0.0	18.75	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	0.0	12.10	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42

O --- OPERATING STATEMENTS ---

O YEAR	21	22	23	24	25	26	27	28	29	30
OGROSS REVENUES	0.0	106.21	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	0.0	108.50	217.00	217.00	217.00	217.00	217.00	217.00	217.00	217.00
MARKET & GENL EXPENSE	0.0	2.37	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	-6.00	-10.66	192.35	192.35	192.35	192.35	192.35	192.35	192.35	192.35
DEPRECIATION	0.0	95.13	95.13	95.13	95.13	95.13	95.13	95.13	95.13	95.26
INCOME BEFORE INTEREST&TAX	-6.00	-105.80	97.22	97.22	97.22	97.22	97.22	97.22	97.22	97.08
INTEREST EXPENSE	21.59	28.52	28.52	26.26	23.87	21.37	18.75	15.99	13.10	10.06
ROYALTY PAYMENT	0.0	0.80	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	-27.59	-135.12	65.51	67.77	70.16	72.66	75.28	78.04	80.93	83.84
DEPLETION ALLOWANCE	0.0	1.20	11.05	11.45	11.87	12.30	12.76	13.23	13.72	14.21
TAX LOSS CARRY-FORWARD	0.0	0.0	54.45	56.32	58.29	57.78	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	-27.59	-136.32	0.0	0.0	0.0	2.57	62.53	64.81	67.21	69.63
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	1.07	25.89	1.00	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	0.0	0.0	0.0	0.0	0.0	0.09	2.85	28.80	30.90	32.01
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	-27.59	-136.32	0.0	0.0	0.0	2.48	59.68	36.01	36.31	37.62

O --- CASH FLOW SUMMARIES ---

NET INCOME	-27.59	-136.32	0.0	0.0	0.0	2.48	59.68	36.01	36.31	37.62
DEPRECIATION EXPENSE	0.0	95.13	95.13	95.13	95.13	95.13	95.13	95.13	95.13	95.26
DEPLETION ALLOWANCE	0.0	1.20	11.05	11.45	11.87	12.30	12.76	13.23	13.72	14.21
TAX LOSS CARRY-FORWARD	0.0	0.0	54.45	56.32	58.29	57.78	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	178.38	183.16	89.84	47.62	50.01	52.51	55.13	57.89	60.78	63.82
CASH FLOW	-205.97	-223.15	70.80	115.28	115.28	115.19	112.43	86.48	84.39	83.27
OPLAN DEBT/EQUITY RATIO	1.00	1.00	0.85	0.72	0.60	0.49	0.39	0.30	0.21	0.14
EARNING FROM MINING	-12.10	-50.96	11.05	11.45	11.87	12.30	12.76	13.23	13.72	14.21
CUMULATIVE DISCOUNTED TAX	0.0	0.0	0.0	0.0	0.0	0.01	0.25	2.44	4.59	6.60
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

O YEAR	31	32	33	34	35	36	37	38	39	40
OCOMMODITY SALES(LBS X 1MILLION):										
NICKEL	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60
OCOMMODITY REVENUES($ X 1MILLION):										
NICKEL	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42	48.42

O --- OPERATING STATEMENTS ---

0 YEAR	31	32	33	34	35	36	37	38	39	40
0GROSS REVENUES	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	217.00	217.00	217.00	217.00	217.00	217.00	217.00	217.00	217.00	217.00
MARKET & GENL EXPENSE	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	192.35	192.35	192.35	192.35	192.35	192.35	192.35	192.35	192.35	192.35
DEPRECIATION	95.26	21.88	21.88	21.88	21.88	21.88	21.88	18.66	18.66	18.66
INCOME BEFORE INTEREST&TAX	97.08	170.47	170.47	170.47	170.47	170.47	170.47	173.69	173.69	173.69
INTEREST EXPENSE	6.87	3.52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	87.03	163.76	167.28	167.28	167.28	167.28	167.28	170.50	170.50	170.50
DEPLETION ALLOWANCE	14.75	20.46	20.39	20.39	20.39	20.39	20.39	20.65	20.65	20.65
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	72.28	143.30	146.89	146.89	146.89	146.89	146.89	149.85	149.85	149.85
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX	33.23	65.90	67.55	67.55	67.55	67.55	67.55	68.91	68.91	68.91
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	39.05	77.40	79.34	79.34	79.34	79.34	79.34	80.94	80.94	80.94

0 --- CASH FLOW SUMMARIES ---

	31	32	33	34	35	36	37	38	39	40
NET INCOME	39.05	77.40	79.34	79.34	79.34	79.34	79.34	80.94	80.94	80.94
DEPRECIATION EXPENSE	95.26	21.88	21.88	21.88	21.88	21.88	21.88	18.66	18.66	18.66
DEPLETION ALLOWANCE	14.75	20.46	20.39	20.39	20.39	20.39	20.39	20.65	20.65	20.65
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	67.01	70.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CASH FLOW	82.05	49.40	121.61	121.61	121.61	121.61	121.61	120.25	120.25	120.25
0PLANT DEBT/EQUITY RATIO	0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	14.75	37.56	38.70	38.70	38.70	38.70	38.70	40.43	40.43	40.43
CUMULATIVE DISCOUNTED TAX	8.51	11.94	15.14	18.05	20.69	23.10	25.28	27.31	29.15	30.83
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

--- SALES ANALYSIS ---

0 YEAR	41	42	43	44	45	46
0COMMODITY SALES(LBS X 1MILLION):						
NICKEL	73.40	73.40	73.40	73.40	73.40	73.40
COPPER	60.00	60.00	60.00	60.00	60.00	60.00
COBALT	8.60	8.60	8.60	8.60	8.60	8.60
0COMMODITY REVENUES($ X 1MILLION):						
NICKEL	275.24	275.24	275.24	275.24	275.24	275.24
COPPER	75.00	75.00	75.00	75.00	75.00	75.00
COBALT	48.42	48.42	48.42	48.42	48.42	48.42

0 --- OPERATING STATEMENTS ---

0 YEAR	41	42	43	44	45	46
0GROSS REVENUES	424.83	424.83	424.83	424.83	424.83	424.83
COST OF GOODS SOLD	217.00	217.00	217.00	217.00	217.00	217.00
MARKET & GENL EXPENSE	9.47	9.47	9.47	9.47	9.47	9.47
R&D/P&E EXPENSE	6.00	6.00	6.00	6.00	6.00	6.00
GROSS PROFIT	192.35	192.35	192.35	192.35	192.35	192.35
DEPRECIATION	18.66	8.97	8.97	8.97	8.97	8.97

INCOME BEFORE INTEREST&TAX	173.69	183.38	183.38	183.38	183.38	183.38
INTEREST EXPENSE	0.0	0.0	0.0	0.0	0.0	0.0
ROYALTY PAYMENT	3.19	3.19	3.19	3.19	3.19	3.19
EARNING OF FOREIGN CORP	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX&CREDITS	170.50	180.19	180.19	180.19	180.19	180.19
DEPLETION ALLOWANCE	20.65	21.48	21.48	21.48	21.48	21.48
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0
INCOME BEFORE TAX	149.85	158.71	158.71	158.71	158.71	158.71
INVESTMENT CREDIT	0.0	0.0	0.0	0.0	0.0	0.0
CREDITABLE UN TAX	0.0	0.0	0.0	0.0	0.0	0.0
TAX	68.91	72.99	72.99	72.99	72.99	72.99
FORIEGN TAX CREDIT	0.0	0.0	0.0	0.0	0.0	0.0
NET INCOME	80.94	85.72	85.72	85.72	85.72	85.72

--- CASH FLOW SUMMARIES ---

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NET INCOME	80.94	85.72	85.72	85.72	85.72	85.72
DEPRECIATION EXPENSE	18.66	8.97	8.97	8.97	8.97	8.97
DEPLETION ALLOWANCE	20.65	21.48	21.48	21.48	21.48	21.48
TAX LOSS CARRY-FORWARD	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL INVESTMENT	0.0	0.0	0.0	0.0	0.0	-405.37
CASH FLOW	120.25	116.18	116.18	116.18	116.18	521.55
OPLANT DEBT/EQUITY RATIO	0.0	0.0	0.0	0.0	0.0	0.0
EARNING FROM MINING	40.43	45.91	45.91	45.91	45.91	45.91
CUMULATIVE DISCOUNTED TAX	32.35	33.82	35.15	36.36	37.46	38.46
FOREIGN SAVINGS	0.0	0.0	0.0	0.0	0.0	0.0

1DEEP OCEAN MINING STUDY
RUN NUMBER 1 - 1

SUMMARY OF NPV ANALYSIS

NET PRESENT VALUE ($ 1 X 1MILLION)

(AT VARIOUS DISCOUNT RATES)

DISCOUNT RATES	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00
	-11.80	4.60	31.01	72.34	135.90	232.49	378.29	597.56	926.87

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DEEP OCEAN MINING STUDY

SUMMARY

PROJECT	RUN	STARTUP	LIFE (YRS)	TAXR ($X 1MILLION)	SDR	IROR	PAYBACK	COMMENTS
1	1	1	46	$ 0.0	(10.00%)	9.21%	14.7 YRS	

IDENTIFICATION OF SELECTED INPUT VARIABLES FOUND IN PROGRAM PRINTOUT

SYMBOL	DEFINITION
ARO	Annual Rate of Ore Recovery
KINVST	Investment Period
KOPS	Operating Period
KPE	Exploration Period
KRD	R & D Period
LD	Variable used to set mode of tax calculation LD = 0 neutral foregin tax = 1 pre-tax calculation (no tax) = 2 excess foreign tax credit = 3 economic income calculation
LDADR	Variable used to determine service life of mining and and transport equipment LDADR = 0 KOP governs = 1 20% shorter ADR
LDEX	Variable used (together with MORTZ) to determine tax treatment of P & E costs LDEX = 0 ore treated as foreign deposit ≠ 0 ore treated as domestic deposit
LDITC	Variable used to determine qualified property for investment tax credit purposes LDITC = 0 processing equipment only = 1 processing and mining equipment = 2 processing, mining, and transport equipment NOTE: This variable does not conflict with INOITC but rather works in conjunction with it.
LDFTC	Variable used to determine tax treatment of revenue sharing payments to authority LDFTC = 0 no foreign tax credit allowed = 1 foreign tax credit for authority payments
LDORG1	Variable used to set mode of investment in processing activity LDORG1 = 1 corporate viewpoint = 2 investor as partner = 3 investor as stockholder

SYMBOL	DEFINITION
LDORG2	Variable used to set organizational form of mining and transport activity LDORG2 = 1 mining and transport activity conducted by processing entity = 2 transport activity conducted by foreign corporation = 3 mining and transport activity conducted by foreign corporation
MORTZ	Amortization of P & E indicator MORTZ = 0 expense as much as law allows dependent on whether ore deposit is in the U.S. (i.e. domestic) = 1 capitalize all P & E
QMV(J)	Metal Prices J = 1 nickel = 2 copper = 3 cobalt = 4 manganese
RE(J)	Metal recovery efficiency J = 1 nickel = 2 copper = 3 cobalt = 4 manganese
SCEF(J)	Startup cost efficiency factor K = year of startup phase
SDR	Social discount rate
SREF(K)	Startup recovery efficiency K = year of startup phase
XIR	Term loan interest rate

2. OUTPUT DATABASE FOR CHAPTER IV

	IRR (%)	ADJUSTED PRESENT VALUE ($MM) 2%	3%	4%	5%	6%	7%	8%	9%	10%
I. Base Case	9.2	926.9	597.6	378.3	232.5	135.9	72.3	31.0	4.6	-11.8
II. Best Case	22.0	3433.6	2424.8	1721.2	1227.5	878.9	631.4	454.7	328.0	236.7
III. Worst Case										
IV. Metals Price Variation										
A. +25% gross revenues	13.9	1684.7	1153.7	789.6	539.0	366.0	246.3	163.3	105.9	66.2
B. -25% gross revenues	2.7	96.5	-28.0	-97.7	-133.2	-147.5	-149.1	-143.4	-133.7	-122.2
C. +25% Ni Price	12.7	1462.7	991.2	669.8	450.0	299.4	196.0	125.2	76.8	43.9
D. -25% Ni Price	4.6	338.5	156.4	44.5	-22.3	-60.2	-79.8	-87.9	-89.0	-86.0
E. +25% Cu Price	10.2	1072.3	704.7	457.8	291.9	180.7	106.3	56.9	24.5	3.6
F. -25% Cu Price	8.2	778.1	487.7	296.6	171.2	89.6	37.2	4.1	-16.2	-27.9
G. +25% Co Price	9.9	1019.4	665.8	428.9	270.4	164.4	94.0	47.6	17.3	-2.0
H. -25% Co Price	8.6	834.4	529.3	327.5	194.5	107.2	50.5	14.3	-8.2	-21.7
I. 1% annual real growth	14.9	2076.3	1425.9	980.1	673.1	461.0	313.9	211.8	140.9	91.6
J. 2% annual real growth	19.8	3639.1	2543.7	1785.8	1258.4	889.3	629.7	446.3	316.1	223.5
K. 1980 base, 0% growth	14.5	1798.3	1236.8	850.8	584.5	400.0	271.8	182.7	120.7	77.6
L. 1980 base, 1% growth	19.6	3245.9	2276.9	1604.0	1134.0	803.9	570.9	405.6	288.0	204.0
M. 1980 base, 2% growth	24.3	5256.4	3714.4	2639.9	1886.1	1354.0	976.2	706.3	512.6	372.8
V. LOS Treaty										
VI. Technological Factors										
A. -10% output, -5% Op. costs	7.5	690.2	423.4	249.1	135.9	63.2	17.3	-11.0	-27.6	-36.7
B. +5% output, +5% Op. Costs	9.7	999.4	650.4	417.0	261.1	157.2	88.3	43.0	13.7	-4.9
C. +10% recovery efficiency	11.3	1238.4	826.7	548.2	359.4	231.4	144.7	86.2	47.0	20.9
D. -10% recovery efficiency	6.6	618.2	364.2	199.8	94.7	28.4	-12.2	-36.1	-49.0	-55.0
VII. Delays										
A. 1-year, pre-investment	9.0	903.2	574.6	358.3	216.2	123.2	62.8	24.2	0.0	-14.7
B. 2 year, pre-investment	8.8	880.8	553.0	339.6	201.0	111.5	54.2	18.1	-4.1	-17.2
C. 1 year, intra-investment	9.0	903.2	574.6	358.3	216.2	123.2	62.8	24.2	0.0	-14.7
D. 2 year, intra-investment	8.8	880.8	553.0	339.6	201.0	111.5	54.2	18.1	-4.1	-17.2
E. 1 year, pre-production	7.3	792.1	477.9	274.7	144.3	61.6	10.2	-20.8	-38.3	-47.3
F. 2 year, pre-production	6.6	750.7	435.7	235.3	109.3	31.3	-15.4	-42.2	-56.1	-62.0
G. 1 year, all three points	7.0	752.1	440.8	244.2	121.3	45.6	0.1	-26.13	-40.1	-46.5

2. (Cont'd)

	IRR (%)	2%	3%	4%	5%	6%	7%	8%	9%	10%
VIII. Capital Costs										
A. +25% all costs	7.3	832.4	505.6	292.3	154.2	65.8	10.4	-23.4	-42.8	-52.9
B. -25% all costs	11.3	1031.0	689.1	457.4	300.2	193.4	121.0	72.0	39.1	17.2
C. 1% annual real growth	7.0	783.3	471.9	268.8	137.5	53.6	1.3	-30.3	-48.2	-57.3
XIX. Operating Costs										
A. +25% all costs	5.5	474.2	253.6	114.6	28.5	-23.2	-52.7	-68.0	-74.3	-75.0
B. -25% all costs	12.2	1342.9	906.6	609.6	407.0	268.5	173.8	109.2	65.2	15.4
C. 1% annual real growth	3.9	223.7	78.0	-9.4	-59.5	-86.0	-97.8	-100.5	-97.8	-92.2
XX. Depletion Allowance										
A. No percentage depletion	8.7	837.3	533.6	332.4	199.3	111.7	54.6	18.0	-5.1	-19.0
B. Domestic deposit depletion	9.4	958.3	619.3	393.4	243.0	143.3	77.6	34.7	7.2	-9.9

3. ADDITIONAL MAJOR USER SELECTED VARIABLES

SYMBOL	DEFINITION
BLDR	Lower Limit of Discount Rate Range
BONUS	A first year payment to the authority (financial arrangements)
CAPCST(I,J)	Capital Cost Array I = sector J = subsector
CAPFC(K)	Capital Allocation Factor K = year of investment period
CCSF(I,J)	Capital Cost Sensitivity Factor I = sector J = subsector Used to increase or decrease capital cost on a subsector basis
COMP(I)	Nodule Composition I = 1 - nickel I = 2 - copper I = 3 - cobalt I = 4 - manganese
DERMAX	Debt/Equity Ratio (maximum)
DRI	Discount Rate Increment
DSCFF	Debt Service Cash-Flow Factor
EVARY(K)	Exploration Cost Allocation Factor K = year of exploration period Note: This factor is used to allocate both capitalized and expensed exploration costs
ICFK	First year in which cash flow is not set equal to zero. This factor is used to <u>sink</u> costs and income in years prior to ICFK.
IDLY(I)	Delay Period Lengths I = 1 Pre - R & D Delay I = 2 Pre-Investment Delay I = 3 Intra-Investment Delay I = 4 Pre-Operation Delay I = 5 Intra-Operation Delay

Additional Major User Selected Variables cont'd.../Page 2

SYMBOL	DEFINITION
INOITC(I,J)	Investment Tax Credit Eligibility Factor I = sector J = subsector This indicator matches element for element with the CAPCST(I,J) array and indicates if the subsector capital cost is qualified for an investment tax credit. If INOITC(I,J) = 1 then subsector does not qualify.
INONDP(I,J)	Depreciation Eligibility Factor I = sector J = subsector Works just like INOITC, except determines depreciation eligibility.
IRSP	Financial Arrangements Package Indicator IRSP = 1 -- Richardson profit sharing 2 -- ICNT profit sharing 3 -- Imputed value 4 -- General revenue sharing 5 -- General revenue sharing + some modifications 6 -- (it is not clearly written) 7 -- No financial arrangements
KDP(I,J)	Subsector Depreciation Period I = sector J = subsector
KDPMAX	Maximum Depreciation Period
KLN	Loan Amortization Period
KOP1	Initial Operating Period (Pre-Delay)
KPERM1	First year in which permitting costs (i.e. CAPCST (1,5) & OPCST (1,5) are allocated.
KPERM2	Last year in which permitting costs are allocated
KPP	Prospecting period
KSU	Startup period
KVI	Pre-Investment delay; investment period
METH(I,J)	Subsector method of depreciation I = sector J = subsector METH = 1 sum of years digits = 2 declining balance/straight line = 3 straight line = 4 declining balance

Additional Major User Selected Variables cont'd.../Page 3

SYMBOL	DEFINITION
MPPD	Depletion allowance method selector MPPD = 1 depletion based on value of landed ore (VLO) ≠ 1 depletion based on percentage allowed for particular ore
OCSF(I,J)	Operating cost sensitivity factor I = sector J = subsector Works like CCSF only for operating costs
OPCST(I,J)	Operating cost array I = sector J = subsector
PCSF(I,J)	Preparatory cost sensitivity factor I = sector J = subsector Works like CCSF and OCSF only for preparatory cost (i.e., PRECST(I,J))
PERVAR(K)	Permitting cost allocation factor K = year of permitting period Works for permitting cost in same manner that EVARY(K) works for exploration costs.
PRECST(I,J)	Preparatory period costs I = sector J = subsector
PVARY(K)	Prospecting cost allocation factor K year of prospecting period Works for prospecting costs in same manner that EVARY(K) works for exploration costs.
QMVSF(K,J)	Market value sensitivity factor K = year of project J = 1 nickel = 2 copper = 3 cobalt = 4 manganese This variable allows you to sensitize any metal price in any year, K, of the project life.

Additional Major User Selected Variables cont'd.../Page 4

RDVARY(K)	R&D allocation factor K = year of R&D period
STXRT	State tax rate
TLDR	Upper limit of rate range discount
VLO	Value of landed ore
XIF(K,I)	Inflation rate K = year of project I = 1 investments = 2 revenues = 3 operating costs = 4 discount rate I=1 through I=4 are items to be inflated.
KCONE1	First year of continuing exploration expense allocation
KCONE2	Last year of continuing exploration expense allocation
CONR1	First year of continuing R&D expense allocation
CONR2	Last year of continuing R&D expense allocation
MKFAC	Marketing factor (fraction of revenues allotted for marketing expenses)