An Economic Analysis of a Pioneer Deep Ocean Mining Venture

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ABSTRACT

A 3 million ton per year, three metal, vertically integrated, ocean exploration, mining, transportation and ore-processing and metal-marketing system is defined and the capital and operating costs estimated in 1980 U.S. dollars. A basic return-on-investment "pay-out" analysis model is presented with several alternate cases investigated. A series of tests is performed to determine the system's sensitivity to realistic variations of key costs and schedule.

For a gross investment of almost $1.5 billion, or a fixed capital investment of about $1 billion, an ocean mining system producing nickel, copper and cobalt will yield approximately $415 million in annual revenues, a before-tax profit of about $180 million and an after-tax profit of less than $100 million, providing an unsatisfactory low internal rate of return of approximately seven percent. It is unlikely that ocean mining will be undertaken using the system defined herein at this level of return unless a critical feedstock for a company's major product is produced or a national need for a strategic metal develops. This conclusion is entirely consistent with today's low level of commitment to long-term, capital-intensive natural resource development projects.

ACKNOWLEDGEMENTS

The research upon which this report is based was supported by the Marine Minerals Division of the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce through the National Sea Grant Program. Mr. Amor L. Lane, now assistant director of the Office of Ocean Minerals and Energy, and Mr. Karl Jugel of his staff have provided excellent guidance, asked disquieting questions and constantly encouraged us throughout the program.

We are all indebted to Dr. J.D. Nyhart for his pioneer work at the Massachusetts Institute of Technology in developing the original "Cost Model of Deep Ocean Mining and Associated Regulatory Issues." The extensive use and discussion of the model led to the team effort for its improvement which, in turn, led to the development of a simplified pay-out analysis technique at Texas A&M University.

The clarity and accuracy of the description and cost estimates in the Ore Transportation and Processing sectors of the pay-out analysis are the results of the major contributions of Mr. Benjamin V. Andrews and Dr. Francis C. Brown, respectively. Mr. Andrews is a recognized expert and consultant in the marine transportation field, while Dr. Brown was director of process engineering of the EIC Corporation and a key member of the original Dames and Moore nodule-processing research team. Mr. Phillip Ronald Grulich, a recent recipient of the M.B.A. degree, and Mr. Thomas Jackson Bridges, a recent recipient of

the M.S. degree in Ocean Engineering at Texas A&M, prepared and revised, respectively, the computer program for this analysis.

I sincerely appreciate the quiet and efficient work of Mrs. Joyce Hyden, our secretary, for her many contributions in typing and retyping the report and for the editing and production contributions of the Texas A&M Sea Grant College Program.

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INTRODUCTION

The question of the economic feasibility of mining manganese nodules from the floor of the deep ocean has claimed the attention of many during the protracted debate on the Law of the Sea Treaty and the parallel research and development of hardware and techniques to demonstrate the technical feasibility of ocean mining. The economic question was clouded by the totally unrealistic expectations of the world community based on Arvid Pardo's "Heritage of All Mankind" pronouncements and by John Mero's early promotional efforts. The purpose of this research is to add realism to the evaluation process and to estimate the costs of a thoroughly defined program, thereby providing the information necessary to determine economic feasibility.

Background

The 1978 MIT Deep Ocean Mining Cost Model by Dr. J.D. Nyhart [1]* was extensively used, criticized and praised leading to the decision by Mr. Amor Lane of the Marine Minerals Division of NOAA to sponsor work to improve the model. Enlisted to support Dr. Nyhart were Dr. Francis C. Brown, an ore-processing export of EIC Laboratories, Inc., Mr. Benjamin V. Andrews, a marine transportation consultant, and the author, John E. Flipse. The work began in early 1979 and has continued into calendar 1982.

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*Refers to references listed at the end of the paper.

The initial Texas A&M University effort in support of Dr. Nyhart addressed the definition of the Research and Development (R&D), Prospecting and Exploration (P&E) and at-sea mining operations of a hypothetical project. Tasks included preparation of these sectors of an operating scenario and a mining system, and estimation of capital and operating costs. The work products (system definition, costs, etc.) were periodically reviewed with NOAA and delivered to Dr. Nyhart for inclusion in his parametric model as "central values" to the extent that he deemed appropriate. Hence, the revised MIT model should be consistent with the Texas A&M model for this case but may be significantly different in other cases, as well as in scope, detail and purpose.

In mid-1980, the requirements of Public Law 96-283, the Deep Seabed Hard Mineral Resources Act, encouraged NOAA to extend the Texas A&M work to develop a simple "table-top" pay-out analysis to assist the Marine Minerals Division in rapid evaluation of any effects of the regulatory regime, to be established by the Act, on any profit and returns, of a pioneer deep ocean mining venture. The NOAA consultants, and their work product, were then made available to the author (and to MIT) for inclusions in this pay-out analysis.

The tedium involved in making a Discounted Cash Flow analysis (or an Internal Rate of Return analysis) encouraged the use of a computer program to do this calculation. The program was developed and then expanded, naturally, to do the entire pay-out calculation. It was further expanded, through subroutines, to permit the use of various depreciation techniques and was then modified to include the tax law passed in mid-1981 (The Economic Recovery Tax Act of 1981). Alternate programs were developed to account for periodic variations in prices of metals and program delays between completion of the system and putting it into full production.

Objectives

The prime objectives of the research were to thoroughly define a "base case", vertically integrated deep ocean mining system, to document the estimating methodology for the capital and operating costs for the chosen system and to develop a straightforward pay-out analysis method that will accurately calculate any returns from the foregoing system.

The Base Case

The vertically integrated manganese nodule mining and processing system selected as the base case included prospecting and research programs, a hydraulic mining system utilizing two mining ships of moderate size, three bulk transport ships to carry the nodules from the mine to the processing plant, an ore-unloading facility, and a reduction/ammoniacal leaching process plant remote from the port area, with waste disposal at an arid land site some distance from the processing plant.

The metal values of a mine-grade manganese nodule include manganese (30-40 percent), iron (8-10 percent), nickel (1.0-1.5 percent), copper (1.0-1.5 percent) and cobalt (0.1-0.5 percent), as well as silica and 10-20 additional trace elements. The early interest of U.S. metal-producing companies in an alternate source for ore influenced NOAA, among others, to select a system yielding only nickel, copper and cobalt, as the primary products so that the system output would be similar in quantity to a traditional land mine. The decision is logical, as the production of a "nice little" ocean mine which yields 30,000 tons of nickel might produce as much as 600,000 tons of manganese annually, close to U.S. annual consumption. To beg the question of marketing so much manganese, a three-metal mine is a logical approach.

The minesite was chosen in the Clarion/Clipperton fracture zone because of its excellent potential for high assay ores, its proximity to the United States and its familiarity to NOAA and the research team. The U.S. West Coast was selected to keep the system an "All-American" operation, although Hawaii and Mexico could be alternate plant sites.

The Principal Investigator and the Consultants decided that a clearly identified base case should be defined and evaluated to ensure that all cost elements were included, to make these estimates defensible, and to ensure identification of all major components and subsystems of the selected system. The results would then be of value to Dr. Nyhart's continuing cost modeling as a benchmark and to the developing industry, government agencies and other users as a guideline.

A Pay-Out Analysis

An essential element of any development program is a detailed plan for accomplishing its objectives and a careful evaluation of the financial rewards. Lack of detail in the plan suggests that the entrepreneur does not know enough to provide a basis for making a reasonable judgement. On the other hand, too much detail may circumscribe the program, leading to endless argument during its execution, with accompanying doubts. The estimation of financial reward, commonly called the "pay-out" study or analysis, presents similar problems.

If the capital and operating costs of a project are known or can be accurately estimated, and if the prices of the products or services can be forecast with confidence, the rate of return on the capital investment is easily determined. If the cost of the money invested is to be considered, the determination of return requires a discounted cash flow or internal rate of return calculation. Obviously, the pay-out analysis results are only as accurate as the forecasts of costs, interest rates, taxes and other input data. Needless complication of the pay-out analysis for the sake of "completeness" often compounds the problem, invites broad but valid criticism and may obscure the basic question.

In an attempt to avoid these pitfalls, the author has prepared a limited but focused pay-out model that permits variation of costs, taxes and revenues but omits leverage, organizational tax shelters, fluctuating interest rates, etc. The method is most frequently used by a corporation to compare several projects with a "best investment" selection as the objective. The refinements are often "left to the accountants" to compensate for underestimated costs, unanticipated changes, delays in program execution (including regulatory hearings, Environmental Impact Statement and lawsuits) and other real-world hazards to even the most carefully planned long-term project. The pay-out analysis reported herein was designed to be a "simple" comparative analysis technique. It has been modified (complicated) only if a simplifying assumption would severely affect the accuracy of the results, recognizing the universal tendency to use such a model to make feasibility judgements. The reader is warned not to use the absolute values of the calculated rate of return unless he understands and agrees with the stated caveats and assumptions and shares the author's evaluation of the risks involved.

In summary, our objectives are to define a vertically integrated, deep ocean manganese nodule mining program, to prepare a documented estimate of capital and operating costs, and to design and use a simple pay-out analysis model to evaluate returns from the selected system.

AN OCEAN MINING PROGRAM, DESCRIPTION AND COST ESTIMATES

The hypothetical ocean mining program described herein is based on a "pioneering" approach in which the responsible parties are competent technical and business professionals who, after careful evaluation, would use all published material on the subject, knowledgeable consultants and experienced engineering service organizations, but who would not "join" an ongoing consortium now involved in ocean mining. The organization of the program is shown in Figure 1.

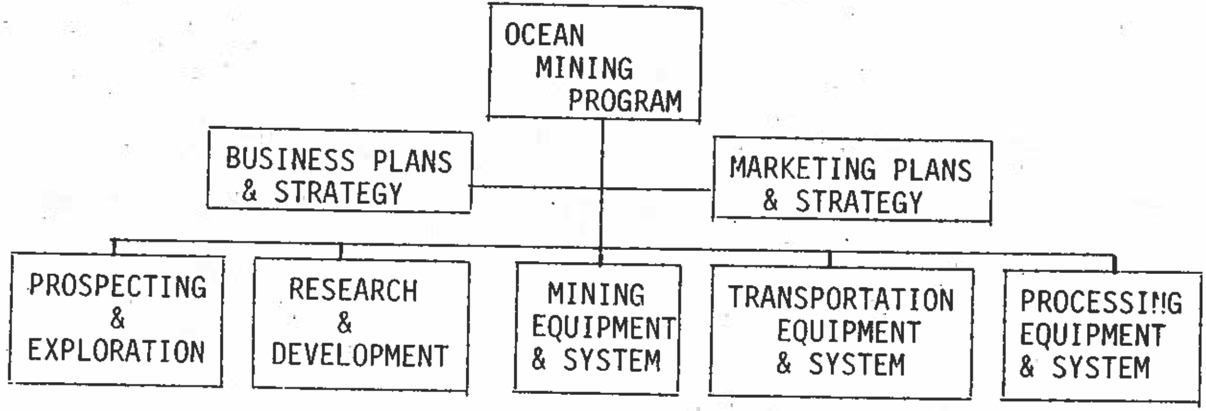

Figure 1. An ocean mining program.

During the initial work with Dr. Nyhart, the author and consultants paid much attention to defining the hypothetical vertically integrated company. The MIT scenario "Toward Deep Ocean Mining in the Nineties" (see Appendix A) describes, in general, the mining venture analyzed herein although Dr. Nyhart and his colleagues sometimes used different methods. It also provides, in some detail, much of the background of the alternate approaches. The following system description does not specifically identify these differences but does provide the user a clear definition of the system subjected to this pay-out analysis.

Although many schedule variations are possible, and perhaps likely, the time value of money suggests that once an organization has decided to "go commercial" (the GO/NO GO decision), every effort will be made to get into production as soon as possible. Hence, a long preparatory period, followed by a minimum construction period, will result in the realistic schedule for the hypothetical ocean mining program shown below. The 20-year production period was chosen so that equipment replacement schedules and costs would not have to be estimated, thereby greatly simplifying the pay-out analysis without severely compromising its accuracy.

GO/NO GO

Preparatory Period	Construction	Production
R&D; P&E; Evaluation	Design, procure, construct, test system	Mine and process nodules; sell products
10-20 years	6 years	20 years

Figure 2. Schedule.

Research and Development (Sector 1)*

Most U.S. corporations have a "long range planning" capability in the form of a company officer, a committee of the Board of Directors

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*During the joint effort with Dr. Nyhart, the several researchers and the sponsor agreed to a "bookkeeping" method dividing the program into logical task groups called "sectors." The sectors (numbered 1 through 9) were further divided into sub-sectors and sub-sub-sectors to assist the estimating process and minimize omissions.

or a consultant to the Chairman of the Board and/or the Chief Executive Officer. It is assumed that this entity has investigated Deep Ocean Mining to the extent that the C.E.O. will authorize, with Board approval, $3-$5 million for a two-year preliminary R&D effort to:

1. Organize a research team headed by a capable manager;
2. Search the literature;
3. Interview officers of companies currently engaged in ocean mining (at any phase);
4. Complete a patent search;
5. Perform simple bench tests in nodule processing/metal winning;
6. Perform simple bench tests (or witness vendor/supplier bench demonstrations) of "ocean mining" equipment;
7. Study the manganese, nickel, copper and cobalt markets to forecast future key metal prices;
8. Design, test and use a simple pay-out model consistent with <u>their</u> business and financial practices to determine the potential rewards of deep ocean mining; and
9. Prepare a plan (schedule and budget) for a major R&D program.

The above activity may precede the "Preparatory Period" P&E and R&D called for in the schedule, or it may be done during the first two years of that period.

Assuming that the findings of this first effort are favorable and that corporate interest is sustained or heightened, approval of the R&D program to be conducted over a 10-year period for approximately $140 million can be expected. Such a program would entail:

1. Component and subsystem tests of the marine mining sector leading to,

- A one-fifth (approx.) scale test of the mining system at sea producing,
- Tens of thousands of tons of nodules to be used in process development;

2. Mini-pilot plant testing of the chosen process(es) followed by,
   - A one-tenth to one-twentieth (approx.) scale demonstration plant of the chosen process at the selected processing plant site yielding,
   - Metal tonnage for market testing, product evaluation and future sales contracts;
3. Refined cost estimates leading to further runs of an enhanced pay-out model; and
4. Preparation of contract plans and specifications for the mining equipment and system, transportation equipment and system, and the processing equipment and system.

With the decision to "GO" into the construction phase of the program, it is reasonable to expect that some leaders/managers of the R&D effort would be selected to supervise the Design, Contract/Procure, Build, Test and Start-Up phases of the program. Others would continue with further R&D while doubling as a "brain-trust" and, when difficulties are inevitably encountered, as the "fire department" or "rescue squad."

Unfortunately, in the early years of the program the "trouble shooting" requirements might severely dilute the continuing R&D work so essential to the optimization of a new technology. It would be prudent to provide for continuing R&D funding from "GO" to the end of year six at a level of approximately one percent of Full Production sales (projection), but in no case less than $2 million per year with subsequent R&D covered by earnings throughout the balance of the program. These costs are provided for in our pay-out analysis.

The estimated cost of the R&D program is shown on page 126 of this report, while the estimated cost for R&D during the construction phase is provided for in Sector 1 of "Costs to be Written Off" on page 130. These values represent a "consensus" figure development during the Nyhart dialog.

Prospecting and Exploration (Sector 1)

An early technical problem facing the ocean miner is prospecting for, locating, defining, mapping and evaluation one or more seabed deposits of manganese nodules. The current literature on the genesis and distribution of this surficial mineral has greatly simplified the early "hunt" for a deposit, but extensive "wide-grid" observations are necessary to define and evaluate the mineability of a discovery. Although there are some improved oceanographic tools, many of the techniques used today to determine the quantity and quality of a manganese nodule deposit are rather state-of-the-art, while some are truly antique.

A first requirement is a ship to provide a working platform, hotel, and transportation to and from the area to be explored. This ship would normally be small (about 150 feet long), of high endurance (30-plus days), diesel-propelled, seaworthy and slow. A ship measuring less than 300 register-tons avoids stringent manning and operating regulations and, if operated prudently, will prove satisfactory as a working platform. Photography, television, and sampling by grabs, box corers or dredges provide data on nodule coverage and population, as well as samples for later analysis and assay. The box cores may also provide soil/sediment data for scientific correlation and mining equipment design. The vessel is kept on position by careful use of thrusters and main propulsion, while buoys and celestial, LORAN, or satellite navigation help to locate the ship on the ocean. Normal oceanographic data for scientific or engineering purposes are obtained by standard equipment. The dearth of synoptic sub-surface deep ocean current or directional wave data suggests that reliable, accurate, and long-lived equipment is needed to acquire these data.

After a deposit is judged to be mineable a "close grid" survey is conducted to confirm the judgement and provide data for preparation of a "mining plan." The seabed topography and the presence of obstacles must also be determined. Measurement of topographic relief of the seabed from the sea surface is inherently inaccurate because of the limitations of the acoustic techniques employed. Towing a transducer near the ocean floor to supply accurate microtopographic information slows the process severely due to cable drag and "flying" of the transducer vehicle. Hence, good data are expensive because excellent equipment, skills, personnel and much time are required to collect them.

To ensure retention of the skilled team and maintenance of the equipment, exploration will continue for the duration of the program. Details vital to the mining plan will be obtained on a timely basis, servicing the seabed acoustic range will be a periodic chore, and prospecting for future mine sites would utilize any "available" time. Ten one-month voyages per year would be full usage.

The estimated cost of the P&E program is shown on page 126, while the estimated cost for P&E during the Construction Phase is provided for as the balance of Sector 1 of "Cost to be Written Off" on page 130. These values are also a "consensus" figure developed during the Nyhart dialog.

The business and marketing planning personnel and the management and technical team needed to supervise and evaluate the preparatory period activities are a well-compensated, high-competence, slowly expanding group of professionals working in rented quarters using rented equipment. These costs are provided for as "G&A" in Appendix B. The work described in the preparatory period will be continued during the six-year design, procure, construction and test time span. It should be noted that this six-year time span assumes technical success at all stages (based on a comprehensive R&D and P&E program) and no incompatible regulatory delays.

This analysis provides no capital funding because offices, piers, ships and equipment continue to be rented (as in R&D and P&E), but it does provide $6 million per year (Appendix B) for this six-year period. The same amount is allowed annually over the life of the project (Appendix B), in which P&E and R&D missions are tailored to developing program requirements.

Mining (Sector 2)

The Mining Equipment and System sector of the hypothetical deep ocean mining program is presented herein in sufficient detail to identify the system elements and their capital and operating costs. The broad narrative version of this sector is presented in Appendix A.

Mining Ships (Sub-sector 2.1)

This hypothetical system requires two ocean mining ships (as a conservative approach) to mine 4.5 million tons of wet nodules annually. This ship characteristics are:

LBP: 789 ft
Beam: 145 ft
Hull Depth: 56 ft
Draft: 42 ft
Loaded Displacement: 105,000 long tons
Cargo Deadweight: 75,000 long tons
Mining Equipment: 11,000 long tons
Light Ship Displacement: 19,000 long tons
Shaft Horsepower: 21,000 diesel electric
Sea Speed: 14 knots
New construction, U.S.A.

The ships are draft-limited because of U.S. port limitations, which slightly increases their cost. They are also capable of being ballasted to full draft, permitting better ship control and surface reference during mining and/or transferring nodules. The ship hulls are strengthened because of the density of the ore.

Main propulsion and power for maneuvering, mining, ballasting and transfer of ore are supplied by multiple high-voltage A.C. generators driven by diesel engines. Each mining ship is twin-screw, fitted with controllable-pitch propellers and multiple retractable thrusters, foreward and aft. A 40-ft by 50-ft "moon pool" is provided. Relatively "lush" accommodations are provided for 80 persons, including ship's and mining crews. Each ship's navigation and communication system includes Satellite, Telex, Weather Fax and a long-base-line bottom acoustic system but does not include an automated ship-positioning system. The latter will be added only if required and cost-effective. A helo-pad is provided.

Our estimating method for the mine ship sub-sector was to examine current bulk-carrier costs (published and unpublished) and modify them to provide for the mining ship differences. The results, on a per ship basis, in 1980 U.S. dollars, are:

Mine Ship:	Basic ship	$60.0 million
	Hull modifications	5.2
	Machinery modifications	8.8
	Navigation and communications	0.9
	Special hotel	2.0
	Shops	1.4
	TOTAL	$78.3 million

Handling and Stowage (Sub-sector 2.2)

Costs for the handling and stowage of mining equipment aboard the mining ship are significant and easily "lost" unless identified and listed separately. They include a 25-ton, 60-ft outreach bridge or pedestal crane for launching and retrieving the collector, winches and racks for handling the hose used to connect the collector to the dredge pipe, special handling of the in-line dredge pumps, and stowage and handling of the long-power and signal cables essential to the operation of the system. Other major components of this sub-sector cost are the dredge pipe rack, pipe transfer system, upper and lower derricks, gimbal platform, pipe lowering/lift system, and the heave-compensation system. This system was sized at 3 million pounds capacity.

Our estimating method was to size, identify suppliers and review published and unpublished data to price each sub-sub-sector. The results, on a per ship basis, in 1980 U.S. dollars, are:

Handling and Stowage Equipment:	Collector	$ 0.9 million*
	Hoses	0.6
	Dredge pipe	16.8
	Dredge pumps	0.3
	Power cabling	1.5
	TOTAL	$20.1 million

*Includes stowage for spare collector on board.

Pumping System (Sub-sector 2.3)

The system selected consists of three multi-stage, motor-driven, mixed-flow pumps located in the upper two-thirds of the dredge pipe string. They are configured to pass through the dredge pipe handling system on the gimbal platform. Selection of power cabling and connectors was based on current practice. A mining control-center, providing system data readouts, stress mointoring, TV, and a monitoring and control computer (provided with manual override), is included in this cost center.

Our estimating method involved basic power requirement calculations and analysis of extensive published and unpublished industry data. Parametric analysis was used as a confirmation technique. The results, on a per ship basis, in 1980 U.S. dollars, are:

Pumping System:	Pumping, motors and housing	$ 4.5 million
	Power trans. and cables	4.8
	Control center, monitoring instruments	2.5
	TOTAL	$11.8 million

Dredge Pipe and Bottom Hose (Sub-sector 2.4)

The selected dredge pipe has the following characteristics:

Length: 18,000 ft
Size: 12 inches I.D. (constant diameter)
Couplings: Clamp type
Material: High strength weldable steel

Thickness: 1/2" minimum with stepped increases
Pipe weight: 2,300,000 pounds
Pipe weight with joints: 2,875,000 pounds (increased for design to 3×10^6 pounds)

A 20-ton (wet) deadweight is employed at the lower end of the pipe string, with special pipe sections provided for the deadweight, pump and motor installation, instrument and controls, dump and/or relief valves and attachment of the bottom hose. The pipe is painted on the outside with inorganic zinc and coated on the inside with an abrasion resistant material. The clamp joints include the clamp forgings, bolts, nuts and seal rings. Stand-offs are provided to attach the cables and support the permanently installed non-buoyant fairing or splitter plates.

The "soft connection" between the dredge pipe and the collector is provided by a 1,200-ft-long x 12-inch-I.D. crush-resistant, high-tensile-strength hose. The hose is supported above the bottom by a buoyant fairing and provides a "route" or cable-way for the cables going to the collector.

Our estimating method involved review of published and unpublished industry data, comparisons with oil-field riser data and parametric analysis. The results on a per ship basis, in 1980 U.S. dollars, are:

Dredge Pipe:	Pipe and joints	$13.4 million
	Bottom hose	1.4
	TOTAL	$14.8 million

Collector (Sub-sector 2.5)

The collector must move across the ocean floor at a speed of one to two knots, separating the nodules from the sediments and delivering them to the dredge pipe inlet. A typical collector for the anticipated production of the system would be approximately 60 ft wide. This most proprietary element of the system can slice, pick, wash or levitate the nodules onto ramps, conveyors or ducts to clean them of clinging sediments while delivering them to the dredge pipe. It must be able to negotiate small obstacles (three-foot boulders) while avoiding major obstacles (cliffs, trenches, wrecks). A "smart" collector will temporarily "store" excess nodules (to compensate for bare patches) while it meters into the dredge pipe the correct quantity to assure high productivity without overloading the pipe. Collectors must function for months without requiring repair or recovery from the bottom.

Our cost estimate was based on "experience" but was confirmed by other "experts." The results on a per ship basis, in 1980 U.S. dollars, are:

Collector:	$3.0 million*

*Provides for a spare collector on each ship with spare stowage provided in the "Handling and Stowage" sector.

Ore Handling (Sub-sector 2.6)

This sector was established to insure identification of mining system elements which tended to be "lost" in other sectors. The system includes:

1. A hose-and-pipe subsystem to accommodate the relative ship/gimbal platform movement while transferring the nodule and water mixture to a separator where the water is returned to the sea and the nodules and recaptured "fines" are deposited onto a conveyor;
2. A conveyor system that distributes the nodules and fines to the specially configured holds where they are retained until removed by reclaimers;

3. Reclaimers that deliver the nodules and fines to the stern where they enter a slurry system;
4. A slurry system that transfers the nodules and fines to the ore transports. A hose to transfer fuel from the transport to the mining ship is included in this system.

Our cost estimate was based on unit equipment costs of similar equipment in allied industries with modifications for the ocean mining application. The result, on a per ship basis, in 1980 U.S. dollars, is

Ore Handling:	Pipe-ship conn. including separator	$ 0.5 million
	Conveyor	0.8
	Holds and reclaimer	7.3
	Slurry transfer system, including fuel oil transfer	2.8
	TOTAL	$11.4 million

System Capital Costs

As noted above, each ship is outfitted with a collector and a spare collector stowed on the mining ship. The cost of the two collectors and their handling and stowage is included in the foregoing estimates.

A spare pipe string and two spare bottom hoses are provided for the system but are stowed at the ship operating base. They are not carried on board the mining ships because accidental loss of a pipe string would probably result in damage that would require a trip to the operating base (or shipyard) for repairs. The cost of the spare pipe string (not including engineering) and the two spare bottom hoses is estimated at U.S. $15.9 million.

A summary of the mining system costs follows (Table 1).

Table 1

Summary Cost Estimate for Mining Equipment and System (Sector 2) in Millions of 1980 U.S. Dollars

		COST	
Sub-Sectors	Sub-Sub-Sectors	One Ship Capital	Two Ship System Capital
Mine ship (2.1)	Basic ship	$ 60.0	
	Hull modifications	5.2	
	Machinery modifications	8.8	
	Navigation and communications	0.9	
	Special hotel	2.0	
	Shops	1.4	
	TOTAL	$ 78.3	$156.6
Handling and stowage equip. (2.2)	Collector	$ 0.9(1)	
	Hoses	0.6	
	Dredge pipe	16.8	
	Dredge pumps	0.3	
	Power cabling	1.5	
	TOTAL	$ 20.1	$ 40.2
Pumping system (2.3)	Pumps, motor and housing	$ 4.5	
	Power trans. and cables	4.8	
	Control center, monitoring instruments	2.5	
	TOTAL	$ 11.8	$ 23.6
Dredge pipe (2.4)	Pipe and joints	$ 13.4	
	Bottom hose	1.4	
	TOTAL	$ 14.8	$ 45.5(2)
Collector (2.5)	No breakdown	$ 3.0(3)	$ 6.0
Ore handling (2.6)	Pipe-ship conn. including separator	$ 0.5	
	Conveyor	0.8	
	Holds and reclaimer	7.3	
	Slurry transfer system, including fuel oil transfer	2.8	
	TOTAL	$ 11.4	$ 22.8
	GRAND TOTAL -----		$294.7

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(1) Includes stowage for spare collector on board

(2) Provides for spare pipe string and 2 spare bottom hoses (less engineering) stored ashore.

(3) Provides for spare collector on each ship.

Annual Operating Costs

Annual operating costs were estimated not by labor, energy, etc., but by developing a system-manning roster and fuel-use schedule, applying 1980 industry costs. These costs are estimated as follows:

(a) Manning costs, including a 40-man ship's crew, 32-man mining crew, a full relief crew for each ship (4 full 72-man crews), with provision for overtime, vacation, food and supplies.

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

- (1) Ship: two percent of capital cost;
- (2) Pipe string and collector: 50 percent of capital cost (renew one ship's set each year);
- (3) Other mining and transfer gear: five percent of capital cost.

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

(d) Fuel is U.S. West Coast-delivered #6 ASTM Marine Diesel at $185/long ton (March 1980 quotation). The estimated fuel consumption is:

300 days mining at 16,000 HP or 65 LT/day
54 days transferring nodules at 9200 HP or 37 LT/day
20 days in transit at 13,000 HP or 52 LT/day
15 days in a shipyard -- negligible fuel use
30 days pipe handling at 6800 HP or 27 LT/day
TOTAL fuel usage 23,300 LT/year

Using these values, the estimated annual operating costs are given in Table 2.

Table 2

Annual Operating Cost Estimate for Sector 2
in Millions of 1980 U.S. Dollars

Manning	
Wages, overtime, fringe benefits	
40-man ship's crew	$ 2.6
32-man mining crew	2.0
	$ 4.6
Second crew	4.6
	$ 9.2
Subsistence (6.5/man-day)	$ 0.2
Supplies and stores - ship's crew	0.2
- mining crew	0.6
Subtotal	$10.2
Maintenance and Repair	
Ship (value 73.3x10^{6}x0.02)	$ 1.6
Mining equipment on board (values 31.2x0.05)	1.6
	$ 3.2
Mining equipment - underwater (value 29.6x10^{6}x0.50)	14.8
Subtotal	$18.0
Insurance	
Hull and machinery (value 109.5x0.015)	$ 1.6
P&I @ $1500/person	0.2
Subtotal	$ 1.8
Fuel	
West Coast, Marine Diesel #6 ASTM @ $185/long ton @ 23,300 LT/yr	$ 4.2
Lube oil allowance	0.1
Subtotal	$ 4.3
TOTAL (one-ship)	$34.3
GRAND TOTAL, TWO SHIP SYSTEM -----	$68.6 per year

Ore Marine Transportation (Sector 3)

The capital and operating costs of the marine transportation system were calculated by Mr. Benjamin V. Andrews, a recognized maritime engineering and economics expert, of Menlo Park, California. Mr. Andrews was employed as a consultant to the Marine Minerals Division of NOAA during the early years of the mutual effort but is now a consultant to the author under the terms of an amendment to the Sea Grant project entitled "Ocean Mining Costs." Mr. Andrews' expertise is displayed in the publication "Relative Costs of U.S. and Foreign Nodule Transport Ships" dated April 1978. These data were updated and revised resulting in an ore transportation system of the following characteristics:

Transport Ship Particulars (Sub-sector 3.1)

Number of ships: 3
Length: 750 ft
Beam: 122.5 ft
Depth: 61.5 ft
Draft (S.W.): 41.8 ft
DWT: 68,000 long tons
Speed (loaded): 14.3 knots
Shaft Horsepower: 18,700 HP
Crew: 32 persons
New Construction, U.S.A.

Voyage particulars:

Port to minesite: 1,700 n. miles
Round trip: 3,400 n. miles
Cargo tonnage: 62,000 long tons (90% DWT)
Transit time: 10 days
Loading time: 1 day
Discharge time: 2 days
Delay allowance: 1 day
Voyages per ship per year: 21
Annual usage: 294 days
Annual per ship capacity: 1,650,000 short tons
System capacity: 4,950,000 short tons (vs. 4.5 million short ton requirement)

System Capital Costs

Using the Andrews data, updating to 1980 U.S. dollar costs and providing for the handling of the transfer hoses for fuel oil (to the mining ships) and nodules (to the ore carriers), a ship-board ore distribution system, a helo-pad with fuel service, a full set of spare parts, but no Construction Differential Subsidy, we have a per ship cost (for each of three ships) and a system capital cost, in 1980 U.S. dollars, of:

Ore Marine Transport:		One Ship	Three Ships
	Ship	$57.8 million	$173.4 million
	Helo and handling equipment	.4	1.1
	TOTAL	$58.2 million	$174.5 million

Annual Operating Costs

The annual operating costs were estimated by Mr. Andrews using U.S. crews (ships and helicopters) but no Operating Differential Subsidy, on a per ship basis in 1980 U.S. dollars as follows:

Fixed operating cost (including maintenance and repair)		$3.93 million
Fuel cost		2.52
Port and Lay-up costs		.31
	Subtotal	$6.76 million
Helo crew and fuel (rental)		0.21
	TOTAL	$6.97 million

System Annual Operating Cost ----- $20.9 million

Ore Marine Terminal (Sector 4)

The capital and operating costs of this sector were also estimated by Benjamin V. Andrews and confirmed by the project team. The basic concept is to lease a 15- to 20-acre dedicated waterfront facility on a deep-water harbor of the U.S. West Coast. A lease from a Port Authority for the needed land is a requirement in any modern port while improvements are the responsibility of the user.

Facility Description

The vacant 15-acre site would be graded with water, sewer and electrical services installed. Access roads within the area would be paved. A berth for the 78,000-DWT ships would be dredged, and a suitable pier and pile clusters would be installed. Holding "ponds" for two shiploads of nodules would be provided. Offices for the operating staff, spare parts and stores, and M&R ships would be built. Fuel pipelines (and/or tanks) are provided.

A major element of the cost is the nodule re-slurrying and unloading system, which includes cranes on tracks to handle the unloading gear, stacking gear, and slurry water storage tanks.

System Capital Costs

Using the Andrews data, the above buildings (40,000 ft^2), berth (including $1.75 million dredging allowance), pier, unloading cranes and system cost, in 1980 U.S. dollars, are:

Ore/Marine Terminal:	Pier and berth	$ 9.1 million
	Ore unloading and storage	18.7
	Site improvement	0.9
	Buildings	1.3
	TOTAL	$30.0 million

Annual Operating Costs

The annual operating costs were also estimated by Mr. Andrews. Because of the extensive data he chose to break down his estimates in 1980 U.S. dollars as follows:

Marine terminal	$ 0.2 million
Ore unloading and storage	2.1
Site rent	0.3
Building services (M&R)	0.1
TOTAL	$ 2.7 million

Onshore Transportation (Sector 5)

In developing the ocean mining system scenario we decided, in an attempt at realism, to locate the nodule process plant some distance (25 miles) from the U.S. West Coast port facility and to locate the waste disposal ponds in an arid area remote (60 miles) from the plant. It was also assumed that an access road (five miles long) would be required from the public highway to the plant site (roads within the processing plant are included in that sector), which would be built to comply with local codes and donated to the local government. A five-mile rail spur was also provided. These estimates were also prepared by Benjamin V. Andrews.

System Description

The 25-mile port-to-plant slurry system consists of land (six acres per mile), a port pumping station and several booster pumping stations, a surface slurry pipeline, and a slurry-water return line with required pumps. Seawater (pumped from the harbor) is the slurry medium. The 60-mile plant-to-waste site slurry system includes land and required pumping stations. The fine-particle waste slurry is distributed at the waste site by a piping system included in that sector.

The five-mile rail spur is assumed to be on essentially level ground and includes expensive land ($10,000/acre), a dozen switches and single track to the plant site. The three miles of rail provided within the plant are included in the processing sector. The five-mile, two-lane, "code" highway, capable of carrying heavy loaded trucks, is assumed to cross essentially level terrain. The road land costs are included.

System Capital Costs

Using the Andrews data, we have, in 1980 U.S. dollars:

Onshore Transportation:	Port-to-plant slurry system	$15.2 million
	Plant-to-waste site slurry system	19.9
	Rail lines	3.1
	Access road	1.5
	TOTAL	$39.7 million

Annual Operating Costs

The major element of operating cost in this sector of the system is electricity which is estimated to cost $0.06 per KW hour (March 1980 quotes). Also provided are labor for the pumping stations and pipelines, maintenance and repair (M&R), local taxes, and liability insurance. Using the Andrews data, we have, in 1980 U.S. dollars:

Onshore Transportation:	Port-to-plant slurry system	$4.8 million
	Plant-to-waste site slurry system	2.5
	Rail line	0.2
	TOTAL	$7.5 million

Processing (Sector 6)

The manganese nodules mined in this hypothetical program are processed (reduced to salable products such as nickel, copper and cobalt) using a reduction/ammoniacal leach process. This process was first publicly disclosed in detail in a report by Dames and Moore [2] in 1976-77 and was confirmed as the "best typical" process in broadly attended NOAA sponsored workshops in 1980. Although this process is not likely to be used in an early commercial system by any of the identified consortia, it is a realistic approach to determining the economic viability of an ocean mining program.

The capital and operating costs of the processing system were calculated by Dr. Francis C. Brown, a recognized expert in nodule process engineering, and his associates of the EIC Laboratories, Inc. of Newton, Massachusetts. Dr. Brown was employed as a consultant to the Marine Minerals Division of NOAA during the early years of the mutual effort but is now a consultant to the author under the terms of an amendment to the "Ocean Mining Costs" project.

The selected facility is described in detail in the referenced Dames and Moore report [2]. An adequate description, for identification of cost elements, is presented in Table 3 on page 29. The annual throughput of the plant is three million short tons of dry nodules.

The processing plant sites suggested by the sponsor were the U.S. West Coast or the "big island" of Hawaii. The U.S. West Coast was selected because of "in place" infrastructure and a better estimating data base. The current permitting climate was more or less ignored on the basis that the increasing national need for the strategic metals

Table 3

Nodules Process Plant Capital Cost Breakdown in Thousands of 1980 U.S. Dollars

	Purchased Equip't Cost $M	Factor for Installed Equip't Cost 1.4	Installed Equip't Cost $M	Total Installed Equip't Cost $M	Factor for Physical Plant Cost 1.9	Physical Plant Cost $M	Total Physical Plant Cost $M	Total Plant Costs*
Subsection 3.1: Materials Storage, Handling, and Preparation								
3.1.1 Rail Car Station	190		470					
3.1.2 Coal Stacking, Storage and Reclamation	1,950							
3.1.3 Limestone Stacking, Storage and Reclamation	380		390					
3.1.4 Nodules Receiving and Storage			8,700					
3.1.5 Nodules Reclamation and Transfer	1,730							
3.1.6 Nodules Grinding and Drying	2,080		800					
3.1.7 Lime Storage and Slaking	240		250					
3.1.8 Offgas and Fugitive Control Treatment	4,120							
	10,690	14,970	10,610	25,580	48,600	48,600		72,900
Subsection 3.2: Nodules Reduction and Metal Extraction								
3.2.1 Dried Nodules Feeding and Reduction	1,880		900					
3.2.2 Reduces Nodules Cooling	2,110		600					
3.2.3 Offgas Treatment	2,270							
3.2.4 Reduced Nodules Slurry Aeration	630		90					
3.2.5 Nodules Slurry Leaching - Separation	600		7,120					
	7,490	10,490	8,710	19,200	36,500	30,500		54,600
Subsection 3.3: Metals Separation								
3.3.1 Metals Extraction								
3.3.2 Ammonia Scrubbing						30,000		
3.3.3 Nickel Stripping								
3.2.4 Copper Stripping								
3.2.5 Cobalt Stripping and Solvent Recovery								
								45,000
Subsection 3.4: Reagent Recovery and Purification								
3.4.1 Leached Slurry Washing	290		13,380					
3.4.2 Washed Tailings Stripping	300		370					
3.4.3 Ammonia Recovery - Lime Boil	340							
3.4.4 Process Vent Scrubbing - NH_3 and CO_2	570		1,180					
3.4.5 Wash Solution Reconstitution and Recycle	30		100					
3.4.6 Waste Slurry Storage, Treatment and Transfer	100		840					
	1,630	2,280	15,870	18,150	34,500	34,500		51,700
Subsection 3.5: Metals Recovery and Purification								
3.5.1 Copper Electrowinning; Stripper and Commercial Cells, Starter Preparation, Cathode Handling						22,500		
3.5.2 Copper Electrowinning; Ni Removal								
3.5.3 Nickel Electrowinning; Stripper and Commercial Cells, Starter Preparation, Cathode and Bag Handling						32,800		
3.5.4 Nickel Electrowinning; Cu/Co Removal, Organic Removal								
3.5.5 Mixed Sulfides Precipitation and Separation	950		210					
3.5.6 Selective Leaching and Solution Purification	480		20					
3.5.7 Nickel Reduction and Sintering, Solution Purification	420		20					
3.5.8 Cobalt Reduction and Sintering	1,100							
	2,950	4,130	250	4,380	8,300	63,600		95,400
Subsection 3.6: Plant Services								
3.6.1 Water Supply, Purification			3,080					
3.6.2 Cooling Water System; Towers, Treatment			1,940					
3.6.3 Process Steam System; Boilers, Water/Condensate Treatment, Coal Feeding/Ash Removal						33,200		
3.6.4 Process Gas System - Gasifiers, Gas Cleaning, Energy Recovery, Coal Feeding/Ash Removal						30,100		
3.6.5 Offgas Treatment			4,100					
3.6.6 Plant Power Generation			3,500					
3.6.7 Process Materials, Supplies, Fuel & Product Storage	1,210		570					
3.6.8 Service Buildings — Included in PCC Factor								
3.6.9 Site Services								
	1,210	1,690	13,390	14,880	28,300	91,600	304,600	137,400
								457,200
Land 500 Acres @ $2,000/A								1,000
						Total Fixed Capital Investment		$458,200

*Factor for indirects is taken as 1.5 x physical plant costs.

found in nodules will persuasively displace prevalent inhibiting attitudes. The required land area is 500 acres.

System Capital Costs

The processing sector was divided into six subsectors, which grouped plant operations according to the key functions being carried out. The subsectors were then further subdivided into sub-sub-sectors which were also grouped according to the functions being carried out. The objective of describing the process plant in this amount of detail was to take advantage, wherever possible, of the organization of data in the cost-estimating literature.

The process description and material and energy balances presented in the Dames and Moore report [2] were used as the bases for estimating costs. Design criteria relating to throughput were assigned to each item of equipment, or assemblies of items at the sub-sub-sector level as appropriate, and cost data were obtained for either purchased or installed equipment or for the physical plant costs of sub-sub-sector. Then total plant costs were determined by a factoring technique that estimated, successively, the costs of installed purchased equipment, the costs of commodities involved in supporting installed equipment in the physical plant, and the total physical plant costs for the processing plant. The costs of supplying necessary plant services were estimated separately by the same methodology.

The processing sector capital costs, as developed by Dr. Brown, are shown in Table 3. Summarizing, in 1980 U.S. dollars, we have:

Processing:	Materials storage, handling and preparation	$ 72.9 million
	Nodules reduction and metals extraction	54.8
	Metals separation	45.0
	Reagent recovery and purification	51.7
	Metals recovery and purification	95.4
	Plant services	137.4
	Land	1.0
	TOTAL	$458.2 million

Annual Operating Costs

Annual direct operating costs were estimated from the material and energy balances presented in the Dames and Moore report [2] and from the capital costs previously estimated. Operating costs were considered to consist of those direct costs attributable to materials and supplies consumed in the manufacturing process, purchased utilities and fuel, labor costs, and fixed charges, which are a function of the capital cost of the plant.

Materials and utilities consumptions from the Dames and Moore report [2] and current prices were used to estimate the costs in these accounts. A rough manning table for the plant was developed, and direct labor costs were estimated for each category. Total labor costs were then estimated by adding appropriate allowances for direct fringes and for general and administrative costs associated with plant operation. Costs of maintenance materials and supplies, taxes and insurance were taken as fixed percentages of the total capital cost of the plant.

Dr. Brown and his associates also estimated the annual operating costs of the processing plant. Table 4 presents the breakdown of these costs. In summary, in 1980 U.S. dollars, we have:

Table 4

Nodule Process Plant Operating Cost Breakdown

	Usage	Annual Cost $M/Yr, 1980 $
Materials and Supplies		
$CaCO_3$	26.4 M TPY @ $20/T	528
CaCO	9.3 M TPY @ $32.5/T	302
NH_3	4.0 M TPY @ $190/T	760
H_2S	4.9 M TPY @ $200/T	980
H_2	96 MM SCFY = 32.6 MM BTU/Yr @ $10/MM BTU	326
Cl_2	100 TPY @ $145/T	15
H_2SO_4	670 M GPY = 5.1 M TPY @ $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 75 M GPY:	15 M GPY LIX @ $23/gal 60 M GPY Kerosene @ $1/gal	345 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 and Supplies	3,991 Call $4 MM
Utilities and Fuel		
Coal	775 M TPY @ $45/T ($2/MM BTU)	34,875
POL	500 M GPY @ $1/gal	500
H_2O	1580 MM GPY @ $0.55/M gal	870
Power	188 MM kWh @ $0.06/kWh	11,280
	Total Utilities and Fuel	47,524 Call $47.5 MM

Table 4
(continued)

	Usage	Annual Cost $M/Yr, 1980 $
Labor		
50 Management and Tech/Prof Staff	@ $40 M	2,000
50 Clerical and Administrative	@ $20 M	1,000
50 Operating and Maintenance Supervision	@ $30 M	1,500
50 Senior Operators and Maintenance Personnel	@ $25 M	1,250
250 Operators and Maintenance	@ $20 M	5,000
50 Plant and Operations Support	@ $15 M	750
	Total Direct Salaries	11,500
	Direct Fringes @ 25%	2,875
	Compensation Costs	14,375
	Plant, G,A&O @ 15% C.C.	2,155
	(33 $M/MY)	16,530 Call $16.5 MM
Capital Related Costs (on $458.2 TFC)		
Maintenance Materials	@ 4% TFC	18,328
Operating Supplies	@ 1% TFC	4,582
Patents/Royalties/Fees	----	----
State/Local Taxes	@ 1% TFC	4,582
Insurance	@ 1% FTC	4,582
	7%	32,074 Call 32.1 MM
Estimated Total Direct Operating Cost		100,119 M/Yr Call $100.1 M/Yr

Materials and supplies	$ 4.0 million
Utilities and fuel	47.5
Labor	16.5
Capital related charges	32.1
TOTAL	$100.1 million

Waste Disposal (Sector 7)

In the absence of timely R&D results encouraging at-sea disposal of processing wastes, current land-based evaporative techniques were selected. For 20-year project life, 2500 arid acres were provided for a decant pond and at least 20 100-acre waste ponds. Three of the 20 waste ponds required during the 20-year production period are included in the original capital costs, as is a distribution system to transfer the waste from the slurry pipeline to the decant pond and thence to the waste ponds. The waste disposal system capital and operating costs were estimated by Dr. Francis C. Brown and his associates.

System Capital Costs

Waste disposal sector costs were subdivided into those associated with the initial costs associated with the construction of a decant pond for evaporation of excess waste water, the costs of a distribution system for depositing the waste slurry in the disposal area, and the cost of constructing the waste ponds.

The costs of pond construction were estimated by adding the cost of excavating and leveling the pond area, constructing dikes, installing drainage and monitoring trenches and equipment, installing an impervious liner, and reclaiming the area at the end of its useful life.

Using the Brown data, we have, in 1980 U.S. dollars:

Onshore Waste Disposal:	Land	$ 1.0 million
	Decant pond	2.5
	Slurry distribution system	0.6
	Waste ponds	18.7
	TOTAL	$22.8 million

Annual Operating Costs

Operating costs include labor and materials to build new waste ponds (from year two onward), maintenance and repair, monitoring for possible seepage, and restoration of topsoil (where "natural") and vegetation. Protection of fauna, local taxes and insurance are also provided. Using the Brown data, we have, in 1980 U.S. dollars:

Materials and supplies	$0.3 million
Labor	0.4
New pond construction	6.2
TOTAL	$6.9 million

Additional Support/G&A (Sector 8)

During the development of the project scenario, certain costs did not "fit" the several selected sectors resulting in this "catch-all" sector. Because most of the equipment of the sector is available through chartering or rental, this acquisition technique was usually used. An exception is the crew/supply boat because of the high capacity and speed required, the length of the trip and the large number of "passengers" involved making it "special." Mr. Benjamin V. Andrews made a conceptual design resulting in the estimates used herein. The terminal for this boat is assumed to be rented from the Port Authority of a metropolitan city (San Diego or perhaps Hilo or Honolulu) that will also serve as the base of operations of the chartered research vessel. Crew training for the mining ship and transport personnel will be done by others (the Kings Point research facility or commercial sources) to assure the required ship handling competence.

A "headquarters" staff, housed in rented offices, provides the usual management, financial, legal and marketing services necessary for (or incidental to) the smooth operation of the project. This staff is in addition to the management personnel at the processing plant, the ore terminal and the supply base. Space, facilities, support staff and salaries are provided in preceding sectors for R&D and P&E personnel. The cost of the project's marketing program is estimated at 1.5 percent of total revenues based on two possible approaches:

(1) Sale of product through distributors (worldwide), or

(2) "Take-down" of product by the owners of the project, at a discount.

The third alternate, an "in-house" sales staff, has been eliminated as an initial approach but can be substituted for the above alternates if found cost effective.

Capital Costs

The only non-rented item of the sector is the High-Speed Crew/Supply Boat which, using the Andrews data, is estimated to cost, in 1980 U.S. dollars, $1.3 million.

Annual Operating Costs

Mr. Andrews' estimates of operating costs of the Crew/Supply boat include manning, supplies, fuel, and insurance for two round trips per month between the terminal and the mining ships. A small staff at the terminal would provide the management, clerical and warehouse functions in rented facilities. The Research Vessel operating costs include a crew, relief crew, supplies, fuel and insurance on a schedule of 10 one-month voyages per year. As mentioned earlier, mining ship and transport crews are to be trained by others (to a rigid specification); this sub-sector provides for that training as well as travel, subsistence and the extra personnel required during training.

A high-quality rented office complex (perhaps in the port or processing plant area) with rented equipment is provided in this sector. A management organization is assumed, and realistic pay and incentive budgets are allowed. Utilities, insurance, computer services and extensive travel costs were estimated. Although not as extravagant as many businesses, the mining community experience was used as a basis.

Using the Andrews data, but modifying it in part, we have annual operating costs, in 1980 U.S. dollars, of:

Additional Support/GSA:	High-speed crew supply boat	$ 1.3 million
	Supply terminal	0.4
	Research vessel	3.2
	Crew training	0.7
	Headquarters	4.0
	Commission/fees	6.3
	TOTAL	$15.9 million

Regulatory (Sector 9)

A basic objective of NOAA's search for an accurate "COST MODEL" of an ocean mining project was to realistically determine the effect on the profitability of a pioneer deep ocean mining project of alternate regulatory regimes. The Texas A&M Pay-Out Analysis permits such an evaluation for the "base case," selected by NOAA, using the capital and operating costs shown above. NOAA, or other users of the Pay-Out Analysis, will estimate (or assume) capital and operating costs for this sector in order to compare those returns to the returns where these values are taken at zero. All transportation, port and processing facilities include costs bringing these sectors into full compliance with all local, state and federal environmental laws and regulations.

Two areas addressed by the Deep Seabed Hard Mineral Resources Act (Pub. L. 96-283) that may impose significant cost burdens are means to protect the marine environment and to conserve the resources. Another potential regulatory source of operating cost is procedural regulation. For the purpose of this sector we define these costs as:

(1) Environmental, the capital and operating costs necessary to install and operate equipment in the ocean mining system to protect the environment, at sea and on land, to conform to only the environmental regulations promulgated under Pub. L. 96-283;

(2) Conservation, the capital and operating costs necessary to install and operate equipment in the ocean mining system to meet only the conservation regulations promulgated under Pub. L. 96-283; and

(3) Procedural, the operating costs incurred in meeting only the permitting and licensing regulations of Pub. L. 96-283; this category may include estimated annual costs due to delay of the project after the GO/NO GO decision made at the end of the R&D and P&E periods.

Capital Costs

The regulations to be promulgated under the law are currently undergoing public scrutiny in the review process. The author's analysis, "The Potential Cost of Deep Ocean Mining Environmental Regulation" [3], suggested certain regulations and estimated their cost. Each investigator is expected to use his judgement in estimating capital costs in this sector.

In the Pay-Out Analysis, these costs were taken as zero.

Annual Operating Costs

As in the case of capital costs, each investigator is expected to use his judgement in estimating annual operating costs. The author [3] found that the at-sea environmental protection costs should be insignificant and should not influence returns estimated by this Pay-Out Analysis.

In this base case, these costs were also taken as zero.

Working Capital

Several analyses were made to estimate the working capital required for the hypothetical program. Parameters involved included initial supplies of fuels and reagents, stockpiled manganese nodules, material in process, stockpiled finished products, products in transit, overdue accounts receivable, collection costs, and underestimated start-up costs. Depending on the analyst's experience and courage, the resulting estimates varied widely.

An alternate approach is to assume that the normal stream of income will be delayed for six months or a full year, requiring working capital in the amount of six months' or a year's operating costs. In this analysis, these values would be \$115 million to \$230 million.

If we consider the complicating factor of the extended system test prior to the start of commercial production, inclusion of start-up fuel and reagents in the system test and the stockpiled nodules and product resulting from it, working capital at \$175 million 1980 U.S. dollars is a realistic and conservative value.

Revenues

The determination of revenue for the hypothetical projects is based on several key factors including the assay of the ore, the annual throughput, the efficiency of the metal-winning process, and, or course, the price of each metal. Most of these parameters can be determined by scientific or engineering methods, with the notable exception of metal prices.

A basic decision, discussed in the Introduction, was the selection of an annual throughput of 3 million tons of dry nodules. An equally important decision is the nodule assay to determine the metal content of the three metals selected for production. In this project we used nickel at 1.30 percent, copper at 1.10 percent and cobalt at 0.25 percent, on a dry weight basis. This assay reflects the author's extensive experience and is in general agreement with the literature for "mine-grade" nodules. The efficiency of metal recovery by various processes has been studied in depth. Dr. Brown concurred with the author's suggestion that recovery rates of 95 percent for nickel and copper and 70 percent for cobalt are realistic for the process selected.

Due to the sensitivity of the returns to metal pricess, an extensive researcher/sponsor dialog was conducted to select metal prices for the "base case." The metal prices used, in 1980 U.S. dollars, are based on the following rationale:

- Nickel (at $3.75/lb) has continued to reflect a weak market due to low levels of usage, market inflexibility, development of competition on the supply side, and new production coming on line. Government influence in Indonesia, Africa and Canada has intensified the problem.
- Cobalt (at $5.50/lb) was expected to return to its traditional level above nickel (a limited substitute) after reaching $20-$30/lb in the spot market during interruptions in supply caused by the Zaire rebellion and the Cuban incursion. The price has not yet returned to $5.50, and the metal is a by-product of copper and/or nickel mining and processing and originates in only a few politically unstable countries. Nevertheless, it is unlikely that the price of cobalt will remain twice that of nickel in the long run.
- Copper (at $1.25/lb) was overpriced in 1980 vs. the 75¢-90¢/lb it was bringing. Faced with much higher energy and machinery costs, it was inconceivable that copper could be selling for its 1975 price in 1982. The pressing need for hard currency in Zambia, Zaire, Chile and the other developing countries that produce copper, has continued to depress this market, as has reduced usage due to the recession.

Using these assumptions and allowing three percent for secondary products of the selected process, we arrive at a total annual revenue of $423 million as follows:

Product	Yield (tons)	Sales ($x1000)
Nickel	36,660	$274,000
Copper	31,020	77,550
Cobalt	5,250	57,750
	Subtotal	$410,300
Secondary Products		12,300
	Annual Revenue	$422,600

Summary

The cost breakdown developed in this chapter for the base case system can be summarized as follows:

Table 5

Cost Breakdown
in millions of 1980 U.S. dollars

Sector	Item	Funding Required	Annual Operating Cost
1	Continuing Preparations	--	$ 6.0
2	Mining	$ 294.7	68.6
3	Ore Marine Transportation	174.5	20.9
4	Ore Marine Terminal	30.0	2.7
5	Onshore Transportation	39.7	7.5
6	Processing	458.2	100.1
7	Onshore Waste Disposal	22.8	6.9
8	Additional Support/G&A	1.3	15.9
9	Regulatory	---	---
	GRAND TOTAL	$1,021.2	$228.6

The working capital required is $175 million.
The annual revenues are $422.6 million.

PAY-OUT ANALYSIS

As mentioned in the Introduction, a prime objective of the research was to develop a simple (table-top) analytical technique that would determine any effects of the regulatory regime to be established by Pub. L. 96-283, the "Deep Seabed Hard Mineral Resources Act," on the profit and returns, if any, of a pioneer deep ocean mining venture.

Basic Approach

The Principal Investigator's industrial experience of two decades in the shipbuilding and ocean resource development business strongly influenced the approach to this Pay-Out Analysis technique. Most pay-out calculations are performed in industry to assist the corporate directors and top management in making investment decisions among competing proposals. Hence, as long as the same "formula" is used for all projects under consideration, the relative merits can be fairly judged IF (a large if), the cost and revenue estimates are accurate. The historic low interest rates in the United States from the 1930's until the early 1970's encouraged such comparisons to be made on the "simple return" or "pay-back period," both before and after taxes. With higher interest rates, the real cost of the monies invested also become important resulting in the comparison of Internal Rate of Return (IROR) or Discounted Cash Flow Return (DCFR), again, both before and after taxes.

An inherent risk to the industrial cost estimator and pay-out analyst is the likelihood that if the project is chosen as an investment opportunity he may be chosen to lead the program, whereupon the cost and revenue estimates become budgets, the schedule is set, and "off-we-go." This phenomenon occurs so often that the researchers in this effort instinctively focused a great deal of effort on making documented capital and operating cost estimates. The long-term value of the research may well be these data.

Another industry influence reflected in this Pay-Out approach is the emphasis on Cash Flow with its attention to full and early use of all available tax shelters. The Economic Recovery Tax Act of 1981 was passed in the final months of this research effort resulting in major revision of the depreciation schedules and some improvement of the several returns.

The limiting assumptions in this base case are:

1. The program is a technical and management success.
2. Cost escalation is offset by metal price increases (revenues).
3. The program will not be unduly delayed by the regulatory/permitting process.
4. All equipment functions for the life of the project with necessary replacements provided for as Maintenance and Repair in Annual Operating Costs.
5. Payments to an escrow account under Pub. L. 96-283 are provided.
6. No depletion allowances are claimed.
7. The first six months of operations of the entire system are funded as part of the system Test (in year six).

8. Revenues in the first year of full production are 80 percent of all subsequent annual revenues, but operating costs are not reduced.
9. Metal prices are "normal" rather than artificially high (cobalt at \$20/lb) or low (copper at 65¢/lb).
10. Straightline depreciation is used as the five-year depreciation life for all capital equipment fully protects earning from taxes until this shelter is fully utilized.
11. A 46 percent tax burden (when applicable) is used with no modification for initial earnings.
12. R&D and P&E costs accumulated before the GO/NO GO decision are amortized over the 20-year production period (rather than SUNK).
13. No debt (or leverage) is used.
14. All working capital, land at cost, and 10 percent salvage value of all equipment are recaptured in the last year of the program.
15. The capital and operating costs of any regulatory regime are zero.

These assumptions represent the author's best judgement and, in balance, are not intended to force an unrealistic high or low return on investment.

The Computer Program

The original purpose of the "table-top" pay-out analysis was to determine any effect of the regulatory regime to be established by Pub. L. 96-283, the "Deep Seabed Hard Mineral Resources Act," on the profit and return, if any, of a pioneer deep ocean mining venture. The original "table top" model, which requires a side calculation of internal rate of return, is given in Appendix B.

To facilitate this study a brief computer program has been developed. The program is not intended to account for all possible circumstances that would be faced by a potential ocean mining venture. However, it is designed to give reasonable estimates of expected revenues and returns on investment capital based upon various perturbations to a "baseline" ocean mining venture. The numbers generated from the program are not expected to be used for corporate decision making without taking into account the individual variables unique to a specific case or organizational structure.

The computer program is based on the flow chart shown in Figure 3. Many auxiliary operations are necessary to complete the computation. No attempt will be made to delineate all the "sub-computations" that produce the results, but the program may be leased from Texas A&M University. The program consists of a main program, with five auxiliary subroutines. It is written in FORTRAN IV, requires 33K bytes of computer storage in the Texas A&M AMDAHL 470V-6 computer and requires less than one-half second of computer time to execute.

The Main Program

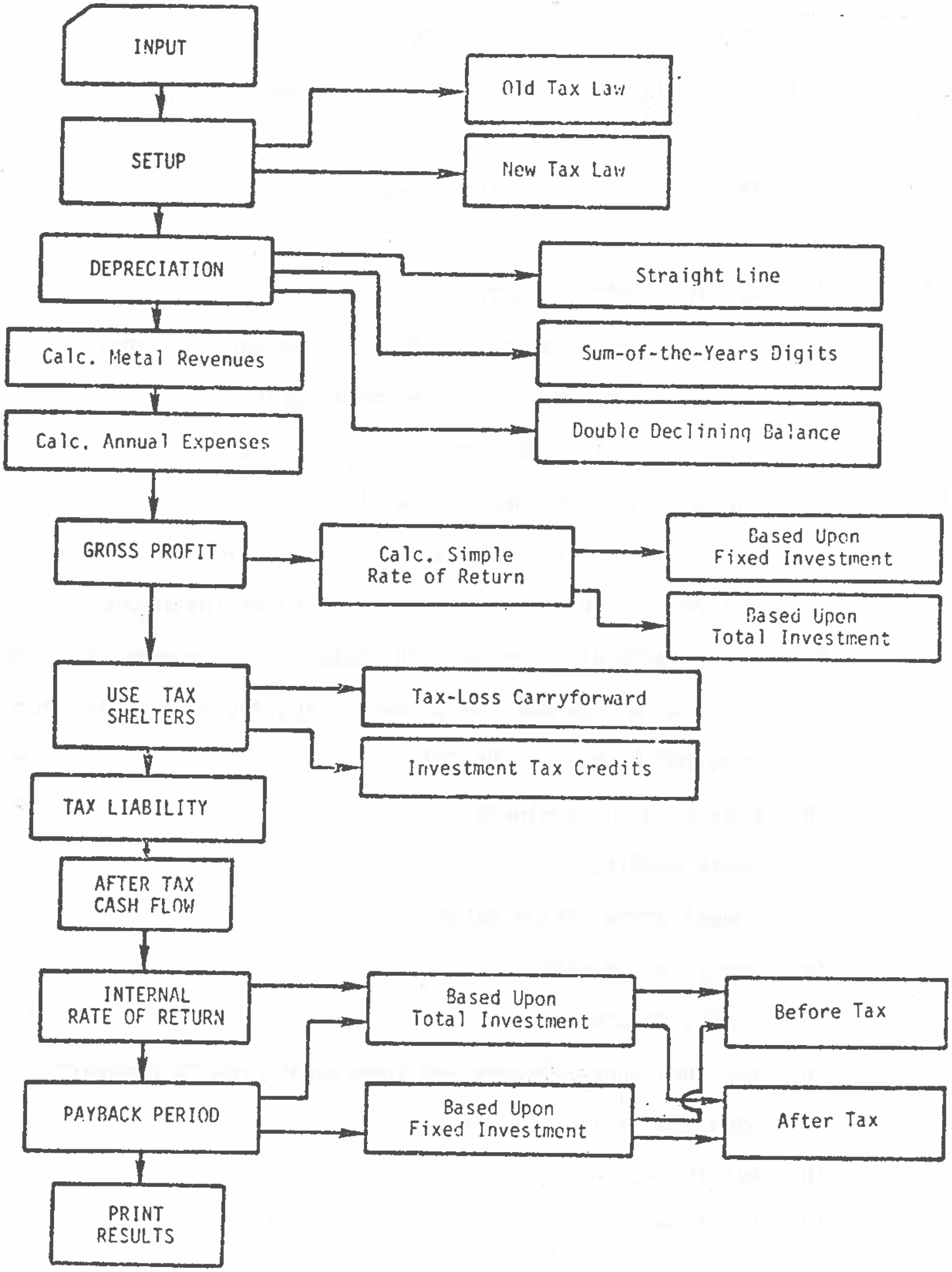
The main program includes the input section consisting of:

(a) Life of the project from start of construction to scraping the system;

(b) Selection of depreciation schedule;

(c) Selection of tax law (pre-1981 or 1981 tax act);

(d) Tax rate;


INPUT
SETUP
Old Tax Law
New Tax Law
DEPRECIATION
Straight Line
Sum-of-the-Years Digits
Double Declining Balance
Calc. Metal Revenues
Calc. Annual Expenses
GROSS PROFIT
Calc. Simple Rate of Return
Based Upon Fixed Investment
Based Upon Total Investment
USE TAX SHELTERS
Tax-Loss Carryforward
Investment Tax Credits
TAX LIABILITY
AFTER TAX CASH FLOW
INTERNAL RATE OF RETURN
Based Upon Total Investment
Before Tax
PAYBACK PERIOD
Based Upon Fixed Investment
After Tax
PRINT RESULTS

(e) Total cost of land;

(f) Mining rate in short dry tons;

(g) Assay and unit prices of nickel, copper and cobalt;

(h) Efficiency of each metal recovery;

(i) Sector annual operating expenses;

(j) Fixed capital required;

(k) Working capital required;

(l) Expenditures prior to starting system construction;

(m) Schedule for influx of investment capital;

(n) Sector costs for depreciation calculation;

(o) Capital influx during the construction period;

(p) Write-offs incurred during the construction period; and

(q) The year in which tax shelters are to be initiated.

The main program also includes the output section consisting of:

(a) Total metal revenues less freight and any escrow payments required by Pub. L. 96-283;

(b) Cost of doing business;

(c) Gross profit;

(d) Annual depreciation taken;

(e) Annual write-offs;

(f) Profit before taxes;

(g) Tax-loss carry forward and investment credits generated, used and still available;

(h) Net income;

(i) Tax liability;

(j) Net income after taxes; and

(k) After tax cash flow.

All the calculations necessary to compute the outputs from the inputs above are included in the main program subject to the following subroutines.

Payback Subroutine

This subroutine calculates the numbers of years and months required to recover the investment. The time value of money is not taken into account in this payback analysis. The subroutine requires three inputs:

- The life of the project, which in the base case is 26 years;
- The amount of investment to be recovered; and
- An array that contains the appropriate cash flow values to recover the investment.

Given these three parameters, the subroutine calculates the returns to the main program the number of years and months until the investment has been fully recovered.

Straightline Depreciation Subroutine

This subroutine calculates a depreciation expense schedule based on the straightline method. The straightline method assumes a constant amount of depreciation for each year of the asset's life and is found by dividing the original cost (less anticipated salvage value, if it exceeds 20 percent of the asset value) by the estimated service life. It offers the advantage of simplicity (an important virtue in preliminary economic studies) but may lead to understating investment profitability when income tax considerations are brought in.

The subroutine requires four parameters to produce the depreciation expense schedule:

- The life of the project, which in the base case is 26 years;
- The number of years (or "tax life") the asset is to be depreciated over;
- The original cost of the asset being depreciated; and
- The salvage value of the asset being depreciated.

Given this information, the subroutine calculates the appropriate depreciation schedule for the corresponding years.

Sum-of-the-Years Digits Depreciation Subroutine

This subroutine calculates a depreciation schedule based on the sum-of-the-years digits technique. This method offers high depreciation charges, along with correspondingly low income tax liabilities, during the assets' early years and is therefore popular. The amount charged in any one year is found by first adding together the digits representing each year in the asset's life; a five-year life, for example, gives a sum of 15: (1+2+3+4+5 = 15). Then a proportion of this total is taken for each. The charge for the first year is 5/15 of the original cost; the second year, 4/15; the third year, 3/15; the fourth year, 2/15; and the last year the remaining 1/15.

This subroutine requires the same parameters as the straightline depreciation subroutine, but calculates the depreciation expense schedule according to the above formulation.

Double Declining Balance Depreciation Subroutine

This subroutine calculates a depreciation schedule based upon the double declining balance method. This method, similar to the sum of the years digits method, offers accelerated depreciation charges during the early years. Depreciation is taken as a constant percentage of the declining account balance, with the rate calculated at twice the corresponding straightline method rate. An asset with a 10-year life, then is depreciated at 20 percent of its undepreciated balance each year. Because the asset is never 100 percent depreciated this way, the undepreciated portion of the account balance is written off the last year.

This subroutine requires the same parameters as the straightline depreciation subroutine, but calculates the depreciation expense schedule according to the above formula.

Internal Rate of Return Subroutine (IROR)

This is a general subroutine that will calculate the internal rate of return of a project. This method accounts for the "time value of money." The IROR calculation returns a value in the form of a percentage. This percentage is the expected return on investment accounting for the expected devaluation of future economic returns from the project. This percentage can be compared to the firm's cost of capital to see if the expected return exceeds the cost of capital or it can be compared to projects of similar risk as an aid in decision making.

The subroutine requires three parameters in order to calculate the IROR:

- The life of the project, which in the base case, is 26 years;
- An array that contains the cash flow for each year of the project; and
- An array which contains the amount of capital which is invested each year; in the base case, capital is invested in years one through six only.

Given these parameters, the subroutine calculates and returns the appropriate internal rate of return as a percentage.

The Base Case

As previously mentioned, a major objective of this research was to accurately define and prepare a documented estimate of the capital and annual operating costs of a practical deep ocean mining system. The earlier work by Nyhart [1] was based on a three metal, 3 million dry ton per year system, hence these values were used for this base case. The base case is described in the prior chapter of this report while a broader description is included in Appendix A.

The Computer Program

The following material is the BASE CASE print-out of the computer program described above. The values are in thousands of 1980 U.S. dollars unless noted otherwise. The depreciation information is arranged in the pre-1981 Tax Law life groups rather than in the 1981 "all five-year-lives" array.

Recapitulation (as printed out)

```
Gross Funding Requirements                     1,494,400.
Fixed Capital Requirements                     1,021,200.
Net Annual Revenue                               451,162.
Sector Operating Costs                           228,638.
Depreciation Expense                              49,219.
Allocation of Write-offs                           8,600.
Profit Before Taxes                              -18,950.
Return on Total Funding                             8.61%
Return on Fixed Capital                            12.60%
Before Tax Payback Period on Total Invest.     19 yrs, 4 mo
Before Tax Payback Period on Fixed Invest.     16 yrs, 8 mo
Internal Rate of Return (26 yrs)                    8.50%
Profit After Taxes                                     0.
After Tax Payback Period on Total Invest.      26 yrs, 0 mo
After Tax Payback Period on Fixed Invest.      23 yrs, 10 mo
Internal Rate of Return (26 yrs)                    7.05%
```

```
              TEXAS A&M UNIVERSITY
            OCEAN ENGINEERING PROGRAM

        DEEP OCEAN MINING PAYOUT ANALYSIS



        PROJECT LIFE (YEARS)              26
        CONSTRUCTION PERIOD (YEARS)        6
        TAXRATE                         0.46



  I.   INVESTMENT INFORMATION
       ----------------------


        1. TOTAL FIXED INVESTMENT                         1021200.
        2. WORKING CAPITAL                                 175000.
        3. CONSTRUCTION PERIOD EXPENSES                    126200.
        4. PREPARATORY PERIOD COSTS                        172000.
                                                         ----------
        5. TOTAL INVESTMENT                               1494400.

        6. SCHEDULE FOR INFLUX OF INVESTMENT CAPITAL

                   YEAR           AMOUNT

                     1             21400.
                     2             65400.
                     3            172000.
                     4            257700.
                     5            353400.
                     6            452500.



 II.   REVENUE INFORMATION
       -------------------


        1. ANNUAL PRODUCTION OF NODULES

                   RECOVERED IN TONS/YEAR                 3000000.

        2. METAL PRICES USED

                   NICKEL ($/LB)                             3.75
```

```
                COBALT  ($/LB)                            5.50
                COPPER  ($/LB)                            1.25

           3. ORE  ASSAY  IN  PERCENT
                NICKEL  ASSAY                             1.30
                COBALT  ASSAY                             0.25
                COPPER  ASSAY                             1.10

           4. EFFICIENCIES  OF  METALWINNING
                NICKEL  PROCESS                           0.940
                COBALT  PROCESS                           0.700
                COPPER  PROCESS                           0.940

           5. ANNUAL  REVENUE  FROM  METALS
                NICKEL  REVENUES                        274950.
                COBALT  REVENUES                         57750.
                COPPER  REVENUES                         77550.
                SECONDARY  REVENUES                      12307.

           6. TOTAL  REVENUE
                GROSS  REVENUE                          422557.
                MINUS  FREIGHT                            4226.
                MINUS  ESCROW  PAYMENT                    3169.
                                                      ----------
                TOTAL  ANNUAL  REVENUE                  415162.


   III.  ANNUAL  OPERATING  COSTS
         ----------------------


           1. CONSTRUCTION  PERIOD  EXPENSES

                YEAR   1                                 10000.
                YEAR   2                                 10000.
                YEAR   3                                 10000.
                YEAR   4                                 10000.
                YEAR   5                                 10000.
                YEAR   6                                 76200.
                                                      ----------
                TOTAL                                   126200.

           2. DURING  PRODUCTION

                SECTOR  1                                 6000.
                SECTOR  2                                68600.
                SECTOR  3                                20900.
                SECTOR  4                                 2700.
                SECTOR  5                                 7500.
                SECTOR  6                               100100.
                SECTOR  7                                 6900.
                SECTOR  8                                15938.
                SECTOR  9                                    0.
                                                      ----------
                TOTAL                                   228638.
```

```
IV.  DEPRECIATION INFORMATION
     ------------------------

     1. DEPRECIATION CALCULATED USING THE STRAIGHT LINE METHOD
     2. ITEMS WITH A FIVE YEAR LIFE

              MINE SHIPS & EQUIPMENT                          294700.
                   PIPE STRING NO. 1                    -      14800.
                   PIPE STRING NO. 2                    -      14800.
              ORE TRANSPORTS                                  174500.
              PORT TO PLANT SLURRY                             13650.
              PLANT TO WASTE SLURRY                            18427.
              PROCESSING PLANT EQUIP                          297900.
              GENERAL & ADMINISTRATIVE                          1324.
                                                          ----------
              TOTAL                                           770901.
              SALVAGE VALUE                                    75247.
     3. ITEMS WITH A FIVE YEAR LIFE

              TERMINAL PIERS & BHDS                             9063.
              PROCESS. PLANT UTILITIES                         92200.
              PROC. PLANT SITE PREP                            14600.
              WASTE DISPOSAL EQUIP.                              500.
                                                          ----------
              TOTAL                                           116363.
              SALVAGE VALUE                                    11636.
     4. ITEMS WITH A FIVE YEAR LIFE

              TERMINAL SITE IMPROVEMENTS                         872.
              HANDLING EQUIPMENT                               18740.
              WASTE DISPOSAL SITE IMPROV.                      21250.
              RAIL LINES                                        2374.
                                                          ----------
              TOTAL                                            43236.
              SALVAGE VALUE                                     4324.
     5. ITEMS WITH A FIVE YEAR LIFE

              TERMINAL BUILDINGS                                1320.
              PROC. PLANT BUILDINGS                            52500.
              WASTE DISP. BUILDINGS                               50.
                                                          ----------
              TOTAL                                            53870.
              SALVAGE VALUE                                     5387.
     6. PREPARATORY PERIOD COSTS TO BE WRITTEN OFF

              TOTAL COSTS                                     172000.
              ANNUAL WRITE OFF                                  8600.
     7. LAND

            COST OF LAND                                        5700.
```

```
            YEAR                        1         2         3         4         5         6
-----------------------------------------------------------------------------------------------
METAL  REVENUES                        0.        0.        0.        0.        0.        0.
   COST  OF  DOING  BUSINESS       10000.    10000.    10000.    10000.    10000.    76200.
GROSS  PROFIT                     -10000.   -10000.   -10000.   -10000.   -10000.   -76200.
   DEPRECIATION  EXPENSE               0.        0.        0.        0.        0.        0.
   WRITE  -  OFF  EXPENSE              0.        0.        0.        0.        0.        0.
EARNINGS  BEFORE  TAXES           -10000.   -10000.   -10000.   -10000.   -10000.   -76200.
-----------------------------------------------------------------------------------------------
TAX-LOSS  CARRYFORWARD  GENERATED  10000.    10000.    10000.    10000.    10000.    76200.
   TAX-LOSS  CARRYFORWARD  USED        0.        0.        0.        0.        0.        0.
INVESTMENT  CREDIT  GENERATED          0.        0.        0.        0.        0.        0.
   INVESTMENT  CREDIT  USED            0.        0.        0.        0.        0.        0.
-----------------------------------------------------------------------------------------------
NET  INCOME                            0.        0.        0.        0.        0.        0.
   TAX  LIABILITY                      0.        0.        0.        0.        0.        0.
NET  INCOME  AFTER  TAXES              0.        0.        0.        0.        0.        0.
AFTER  TAX  CASH  FLOW                 0.        0.        0.        0.        0.        0.
```

```
          YEAR                          7          8          9         10         11         12
------------------------------------------------------------------------------------------------------
METAL REVENUES                      332130.    415162.    415162.    415162.    415162.    415162.
    COST OF DOING BUSINESS          227988.    227988.    228638.    228638.    228638.    228638.
GROSS PROFIT                        104142.    187174.    186524.    186524.    186524.    186524.
    DEPRECIATION EXPENSE            196874.    196874.    196874.    196874.    196874.        0.
    WRITE - OFF EXPENSE               8600.      8600.      8600.      8600.      8600.      8600.
EARNINGS BEFORE TAXES              -101332.    -18300.    -18950.    -18950.    -18950.    177924.
------------------------------------------------------------------------------------------------------
TAX-LOSS CARRYFORWARD GENERATED     101332.     18300.     18950.     18950.     18950.        0.
    TAX-LOSS CARRYFORWARD USED           0.         0.         0.         0.         0.    104264.
INVESTMENT CREDIT GENERATED         102100.         0.         0.         0.         0.        0.
    INVESTMENT CREDIT USED               0.         0.         0.         0.         0.     73661.
------------------------------------------------------------------------------------------------------
NET INCOME                               0.         0.         0.         0.         0.        0.
    TAX LIABILITY                        0.         0.         0.         0.         0.        0.
NET INCOME AFTER TAXES                   0.         0.         0.         0.         0.        0.
AFTER TAX CASH FLOW                 104142.    187174.    186524.    186524.    186524.    186524.
```

```
                YEAR                   19        20        21        22        23        24
---------------------------------------------------------------------------------------------
METAL REVENUES                      415162.   415162.   415162.   415162.   415162.   415162.
   COST OF DOING BUSINESS           228638.   228638.   228638.   228638.   228638.   228638.
GROSS PROFIT                        186524.   186524.   186524.   186524.   186524.   186524.
   DEPRECIATION EXPENSE                  0.        0.        0.        0.        0.        0.
   WRITE - OFF EXPENSE                8600.     8600.     8600.     8600.     8600.     8600.
EARNINGS BEFORE TAXES               177924.   177924.   177924.   177924.   177924.   177924.
---------------------------------------------------------------------------------------------
TAX-LOSS CARRYFORWARD GENERATED          0.        0.        0.        0.        0.        0.
   TAX-LOSS CARRYFORWARD USED            0.        0.        0.        0.        0.        0.
INVESTMENT CREDIT GENERATED              0.        0.        0.        0.        0.        0.
   INVESTMENT CREDIT USED                0.        0.        0.        0.        0.        0.
---------------------------------------------------------------------------------------------
NET INCOME                          177924.   177924.   177924.   177924.   177924.   177924.
   TAX LIABILITY                     81845.    81845.    81845.    81845.    81845.    81845.
NET INCOME AFTER TAXES               96079.    96079.    96079.    96079.    96079.    96079.
AFTER TAX CASH FLOW                 104679.   104679.   104679.   104679.   104679.   104679.
```

YEAR	13	14	15	16	17	18
METAL REVENUES	415162.	415162.	415162.	415162.	415162.	415162.
COST OF DOING BUSINESS	228638.	228638.	228638.	228638.	228638.	228638.
GROSS PROFIT	186524.	186524.	186524.	186524.	186524.	186524.
DEPRECIATION EXPENSE	0.	0.	0.	0.	0.	0.
WRITE - OFF EXPENSE	8600.	8600.	8600.	8600.	8600.	8600.
EARNINGS BEFORE TAXES	177924.	177924.	177924.	177924.	177924.	177924.
TAX-LOSS CARRYFORWARD GENERATED	0.	0.	0.	0.	0.	0.
TAX-LOSS CARRYFORWARD USED	149485.	48934.	0.	0.	0.	0.
INVESTMENT CREDIT GENERATED	0.	0.	0.	0.	0.	0.
INVESTMENT CREDIT USED	28439.	0.	0.	0.	0.	0.
NET INCOME	0.	128991.	177924.	177924.	177924.	177924.
TAX LIABILITY	0.	59336.	81845.	81845.	81845.	81845.
NET INCOME AFTER TAXES	0.	69655.	96079.	96079.	96079.	96079.
AFTER TAX CASH FLOW	186524.	127189.	104679.	104679.	104679.	104679.

```
         YEAR                          25          26
-----------------------------------------------------------------------------------------------
METAL  REVENUES                     415162.     415162.
   COST  OF  DOING  BUSINESS        228638.     228638.
GROSS  PROFIT                       186524.     463818.
   DEPRECIATION  EXPENSE                 0.          0.
   WRITE  -  OFF  EXPENSE             8600.       8600.
EARNINGS  BEFORE  TAXES             177924.     177924.
-----------------------------------------------------------------------------------------------
TAX-LOSS  CARRYFORWARD  GENERATED        0.          0.
   TAX-LOSS  CARRYFORWARD  USED          0.          0.
INVESTMENT  CREDIT  GENERATED            0.          0.
   INVESTMENT  CREDIT  USED              0.          0.
-----------------------------------------------------------------------------------------------
NET  INCOME                         177924.     177924.
   TAX  LIABILITY                    81845.      81845.
NET  INCOME  AFTER  TAXES            96079.      96079.
AFTER  TAX  CASH  FLOW              104679.     381973.
```

Note: For the calculation of simple return, the third year of full production, year 10 (years 1-6 construction, year 7 at 80 percent of production, year 8, 9, 10, etc. at full production) was chosen as typical for normal (pre-1981 Tax Law) depreciation. Later years (year 15+) are used for this calculation in the computer program when depreciation and other tax shelters are completely used. Hence, negative profits before taxes in the beginning years still yield a simple return, as does zero profit after taxes.

Alternate Cases

During this research the author and sponsor have been questioned on the impact of various alternate approaches on the pay-out of a deep ocean mining project. Of the hundreds of possible cases, we have investigated four; a one mining ship, two transport, 1.5 million tons per year project; a case using ships built in the Orient and manned with European crews; a case with the processing plant located at the port; and a case with at-sea disposal of the processing plant wastes. These cases are discussed separately below.

Case 1. A One-Ship, Two-Transport, 1.5 Million Ton Project

The first alternate case considered was a "smaller" operation using a single mining ship, annually producing 1.5 million tons of dry nodules, which required two smaller ore transports instead of the three used in the base case. The cost of the preparatory effort was kept constant, but all capital and operating costs were re-estimated to account for the lower system throughput.

Although capital costs were reduced, the returns were compromised due to loss of the economies of scale. The results in millions of 1980 U.S. dollars, compared to the base case are:

	Base Case	Alternate 1
Gross Funding Requirements	$1,494.4	$989.2
Fixed Capital Requirements	1,021.2	579.8
Net Annual Revenue	415.2	207.6
Sector Operating Costs	228.6	130.6
Depreciation Expense	49.2	28.1
Allocation of Write-Offs	8.6	8.6
Profit Before Taxes (Year 9)	-18.0	-44.0
Return on Total Funding	8.61%	4.08%
Return on Fixed Capital	12.60%	6.95%
Before Tax Payback Period on Total Invest.	19 yrs 4 mo	25 yrs 5 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	19 yrs 5 mo
Internal Rate of Return (26 yrs)	8.50%	4.65%
Profit After Taxes	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	26 yrs 0 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	26 yrs 0 mo
Internal Rate of Return (26 yrs)	7.05%	4.50%

Case 2. Foreign Ship Construction and Manning

The second alternative to the base case considered having all the ships, two mining ships and three transports, built in the Orient (Korea or Taiwan) and manned by foreign personnel (North European Officers and South European crews). Although the current Deep Ocean Mining Law prohibits this arrangement for a U.S. domesticated corporation, the "reciprocal states" language suggests that this approach is possible by incorporating overseas in a reciprocating state. A potential serious problem could be the mixing of foreign crews with the U.S. mining personnel, because no substitution in this area is likely for some years. In any event, application of the 1936 Merchant Marine Act, which provides for both construction and operating differential subsidies, would yield the same savings and enhancement of returns.

The savings in these sectors of the capital and operating costs are significant in the order of 30-50 percent, but improvement of returns is limited because of the three-to-one ratio of processing to marine costs. The results, in millions of 1980 U.S. dollars, compared to the base case are:

	Base Case	Alternate 2
Gross Funding Requirements	$1,494.4	$1,350.0
Fixed Capital Requirements	1,021.2	850.7
Net Annual Revenue	415.2	415.2
Sector Operating Costs	228.6	209.2
Depreciation Expense	49.2	39.3
Allocation of Write-Offs	8.6	8.6
Profit Before Taxes (Year 9)	-19.0	40.0
Return on Total Funding	8.61%	11.70%
Return on Fixed Capital	12.60%	18.57%
Before Tax Payback Period on Total Invest.	19 yrs 4 mo	17 yrs 0 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	14 yrs 5 mo
Internal Rate of Return (26 yrs)	8.50%	10.65%
Profit After Taxes	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	24 yrs 3 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	19 yrs 6 mo
Internal Rate of Return (26 yrs)	7.05%	8.95%

Case 3. Processing Plant in Port

The third alternative to the base case evaluated the effect of locating the processing plant in the port area (where land is much more expensive or must be rented from a Port Authority) to eliminate duplication of port and plant nodule-holding areas and the nodule slurry transfer system. With wastes disposed of at the same arid remote site, the waste slurry system was extended, offsetting some of the savings. As shown below, only modest improvements of returns were achieved. Again, the results are in millions of 1980 U.S. dollars.

	Base Case	Alternate 3
Gross Funding Requirements	$1,494.4	$1,477.1
Fixed Capital Requirements	1,021.2	1,003.9
Net Annual Revenue	415.2	415.2
Sector Operating Costs	228.6	225.2
Depreciation Expense	49.2	48.6
Allocation of Write-Offs	8.6	8.6
Profit Before Taxes (year 9)	-19.0	-13.1
Return on Total Funding	8.61%	8.98%
Return on Fixed Capital	12.60%	13.22%
Before Tax Payback Period on Total Invest.	19 yrs 4 mo	19 yrs 1 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	16 yrs 6 mo
Internal Rate of Return (26 yrs)	8.50%	8.80%
Profit After Taxes	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	26 yrs 0 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	23 yrs 3 mo
Internal Rate of Return (26 yrs)	7.05%	7.30%

Case 4. At-Sea Waste Disposal

The last alternative to the base case considered in this study was for at-sea disposal of processing plant wastes. Current regulations of the U.S. Environmental Protection Agency require that wastes be dumped at a specific site to facilitate monitoring environmental impacts. This researcher has long contended that processing plant rejects (or wastes) must be "cleaned up" to be eligible for at-sea disposal, but once they meet the criteria permitting them to be "dumped" into the ocean, they should be "dribbled" into the ocean as the nodule transport returns to the mining area for her next load of ore. This approach necessitated the use of self-unloading ore carriers, resulting in major port and pier modifications and a de-watering of the wastes to accommodate/equalize ore and waste volumes. In addition, the decision to vary one parameter at a time left us with a waste-slurry return line from plant to port, waste holding ponds to provide flexibility in transport scheduling, and a net increase in capital and operating costs. The results in millions of 1980 U.S. dollars, compared to the base case are:

	Base Case	Alternate 4
Gross Funding Requirements	$1,494.4	$1,502,200.
Fixed Capital Requirements	1,021.2	1,029,000.
Net Annual Revenue	415.2	415.2
Sector Operating Cost	228.6	238.0
Depreciation Expense	49.2	49.8
Allocation of Write-Offs	8.6	8.6
Profit Before Taxes (year 9)	-19.0	-30.5
Return on Total Funding	8.61%	7.91%
Return on Fixed Capital	12.60%	11.54%
Before Tax Payback Period on Total Invest.	19 yrs 4 mo	19 yrs 10 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	17 yrs 1 mo
Internal Rate of Return (26 yrs)	8.50%	7.95%
Profit After Taxes	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	26 yrs 0 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	25 yrs 0 mo
Internal Rate of Return (26 yrs)	7.05%	6.65%

Two subsets to the above alternative were also considered but not evaluated. The use of tugs and barges to haul wastes from the port facility to a fixed at-sea dumpsite involved a trade-off of the waste slurry pipeline and the arid-land disposal pond system against the waste slurry return pipeline, holding ponds at the port facility and the tug-barge equipment needed. Rough estimates indicated that this trade-off would result in a "break-even" or insignificant improvement in returns. The use of an outfall some distance offshore for dumping the plant rejects holds much more promise but was not evaluated for two reasons:

1. Until the wastes are characterized the problem cannot be accurately defined. This work is now being done under NOAA's sponsorship.
2. Oversimplification of the waste "clean-up" procedures could lead to inaccurate cost estimates generating unrealistic expectations compromising the integrity of our work.

Although we recognize that a dollar saved is woth two dollars earned, at-sea disposal of the plant wastes is not likely to affect returns significantly except in selected site-specific cases.

Sensitivity Tests

The weakness and volatility of metal markets, the uncertainty about inflation and interest rates, and the lessons learned from the nuclear power industry's susceptibility to regulatory and judicial delay encouraged the testing of the model to determine its sensitivity to these real-world inputs. And, regardless of the care taken, estimating errors and engineering developments can influence capital and operating cost estimates. The following cases provide insight into the sensitivity of this model, and the system it defines, to variations in these parameters.

Metal Price Variations

Although the pay-out analysis and computer model permit (with minor changes) price variations over time and "by the metal" in this test, we have increased all prices by the same percentage. The results, using the 1981 Tax Law, are shown in Figure 4. The results are not surprising, but any wishful thinking about prices increasing in the future must be tempered by the notion that costs may also increase. Figure 4 indicates the impact of all metal prices increasing while costs remain constant, in the base case.

A second price variation, considered a more likely event, was for copper to remain at $1.25/lb, nickel to increase from $3.75/lb (year 7), to $3.90 (year 8), $4.05 (year 9), $4.20 (year 10), $4.35 (year 11), and

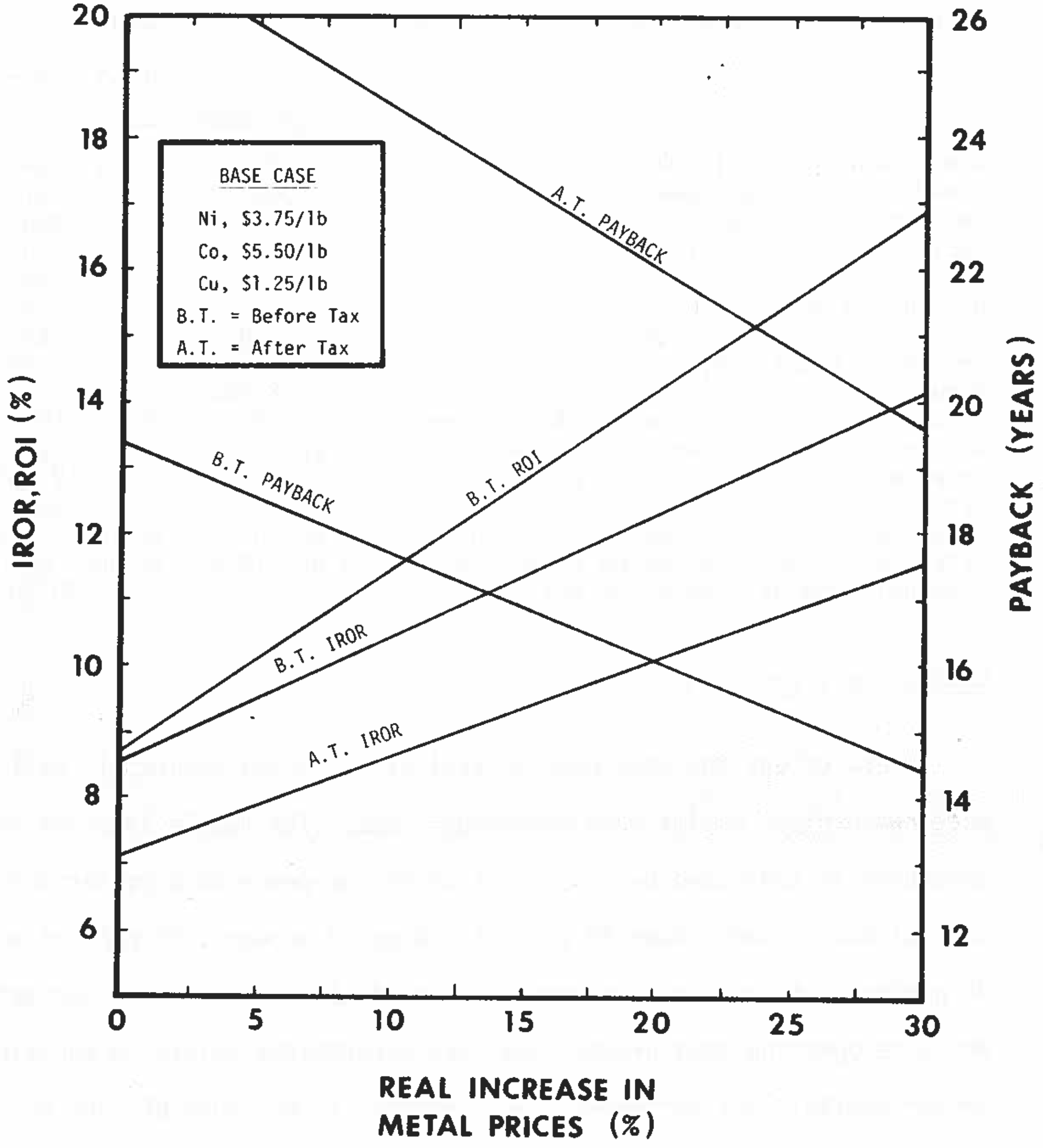


Figure 4. Return vs. metal prices (1981 Tax Law)

$4.50/lb from year 12 onward; cobalt to decrease from $20/lb (year 7), to $17.0 (year 8), $14.20 (year 9), $11.30 (year 10), $8.40 (year 11), and $5.50/lb from year 12 onward. The results of this price variation, compared to the base case, are, in thousands of 1980 U.S. dollars:

	Base Case	"Realistic" Price Variation Case
Gross Funding Requirements	$1,494.4	$1,494.4
Fixed Capital Requirements	1,021.2	1,021.2
Net Annual Revenue	415.2	470.8
Sector Operating Costs	228.6	230.0
Depreciation Expense	49.2	49.2
Allocation of Write-Offs	8.6	8.6
Profit Before Taxes (year 9)	-19.0	94.9
Return on Total Funding	8.61%	12.28%
Return on Fixed Capital	12.60%	17.97%
Before Tax Payback Period on Total Invest.	19 yrs 4 mo	15 yrs 10 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	13 yrs 9 mo
Internal Rate of Return (26 yrs)	8.50%	12.45%
Profit After Taxes	0.	5019.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	22 yrs 3 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	18 yrs 6 mo
Internal Rate of Return (26 yrs)	7.05%	10.20%

Capital Cost Variation

Every effort has been made to realistically and accurately estimate the project capital and operating costs. The team's inherent conservatism is indicated by our selection of the percentage variations of capital costs used: down 10 percent and up 10 percent, 20 percent and 30 percent. Again, we have varied all capital costs the same percentage while recognizing that greater and less uncertainty exists in certain sector capital cost estimates. The results, in millions of 1980 U.S. dollars, are shown in Table 6.

Delay Between System Completion and Use

A truly regrettable but altogether too frequent factor causing

Table 6. Capital Cost Variation

	Down 10%	Base Case	Up 10%	Up 20%	Up 30%
Gross Funding Requirements	$1,392.3	$1,494.4	$1,596.5	$1,698.6	$1,800.8
Fixed Capital Requirements	919.1	1,021.2	1,123.3	1,225.4	1,327.6
Net Annual Revenue	415.2	415.2	415.2	415.2	415.2
Sector Operating Costs	228.6	228.6	228.6	228.6	228.6
Depreciation Expense	44.3	49.2	54.1	59.1	64.1
Allocation of Write-Offs	8.6	8.6	8.6	8.6	8.6
Profit Before Taxes	0.7	-19.0	-38.6	-58.3	-78.4
Return on Total Funding	9.60%	8.61%	7.75%	7.00%	6.32%
Return on Fixed Capital	14.54%	12.60%	11.02%	9.70%	8.57%
Before Tax Payback Period on Total Invest.	18 yrs 9 mo	19 yrs 4 mo	19 yrs 11 mo	20 yrs 6 mo	21 yrs 1 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 1 mo	16 yrs 8 mo	17 yrs 3 mo	17 yrs 10 mo	18 yrs 5 mo
Internal Rate of Return (26 yrs)	9.25%	8.50%	7.80%	7.05%	6.25%
Profit After Taxes	0.	0.	0.	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	26 yrs 0 mo	26 yrs 0 mo	26 yrs 0 mo	26 yrs 0 mo
After Tax Payback Period on Fixed Invest.	22 yrs 2 mo	23 yrs 10 mo	25 yrs 6 mo	26 yrs 0 mo	26 yrs 0 mo
Internal Rate of Return (26 yrs)	7.70%	7.05%	6.50%	5.80%	5.05%

reduction of returns on long-term capital-intensive natural resource and power projects is the inadvertent delay between the time a system is conceived, designed, procured, constructed, tested and then put into service to generate cash flow, and profit. Whether it is a change in market prices, change of royalty levies, corporate indecision, delay of permits or war, the effect often is extremely negative.

In this study we have injected one-year and two-year delays between completion of system tests and putting the system into service. Provision was made for a slight increase in fixed capital (to account for consumed spare parts and component replacement) and an estimated $200 million per year operating cost for maintenance, security, shut-down and start-up, as well as continuing the R&D and G&A programs. A comparison of the results, in millions of 1980 U.S. dollars, follows in Table 7.

Table 7. Impact of Program Delay

	Base Case	1 Year Delay	2 Year Delay
Gross Funding Requirements	$4,494.4	$1,596.4	$1,698.4
Fixed Capital Requirements	1,021.2	1,023.2	1,025.2
Net Annual Revenue	415.2	415.2	415.2
Sector Operating Costs	228.6	230.6	232.6
Depreciation Expense	49.2	49.2	49.2
Allocation of Write-Offs	8.6	8.6	8.6
Profit Before Taxes	-19.0	-20.3	-105.3
Return of Total Funding	8.61%	7.94%	7.34%
Return on Fixed Capital	12.60%	12.38%	12.16%
Before Tax Payback Period on Total Invest.	19 yrs 0 mo	21 yrs 0 mo	22 yrs 9 mo
Before Tax Payback Period on Fixed Invest.	16 yrs 8 mo	17 yrs 9 mo	18 yrs 10 mo
Internal Rate of Return (26 yrs)	8.50%	7.20%	6.15%
Profit After Taxes	0.	0.	0.
After Tax Payback Period on Total Invest.	26 yrs 0 mo	27 yrs 0 mo	28 yrs 0 mo
After Tax Payback Period on Fixed Invest.	23 yrs 10 mo	25 yrs 8 mo	27 yrs 6 mo
Internal Rate of Return (26 yrs)	7.05%	6.50%	6.00%

CONCLUSIONS

As noted previously, the enduring value of this research may well be the documented capital and operating costs estimated for the thoroughly defined base case system. On the other hand, the several alternate cases run and the sensitivity tests performed teach us something, if we do not over-extrapolate their results.

Findings

The Base Case

For a gross investment of almost $1.5 billion dollars or a fixed capital investment of about $1 billion dollars in a complete, vertically integrated deep ocean manganese nodule mining system producing three metals (nickel, copper and cobalt) yielding approximately $415 million in annual revenues, a before-tax profit of about $180 million can be expected. With after-tax profits of about $96 million (after tax shelters are exhausted) the simple return on total investment is 6.4 percent, the payback period exceeds the productive life of the project and the internal rate of return is 7.05 percent.

In a world where investment risks are keyed to multiples of the actual cost of money, a 6.4 percent simple return on investment or a seven percent IROR is entirely unacceptable. The prime rate, or slightly above, is a minimum return for a "no risk" undertaking, while a return of twice the actual cost of money is often the threshold for straight "commercial ventures" where the capital cost and risk is low. Offshore petroleum production (not "wildcatting") frequently demands a return of three times the actual cost of money, while the kindly venture capitalist often expects, and gets, four to five times the actual cost of money.

Hence, we can conclude that a three-metal product deep ocean manganese nodule mining program, at this level of return, will not be undertaken by commercial interests unless the process produces a metal critical to the major product line of the company making the investment. Less the reader conclude that the author has "given up" on manganese nodule ocean mining, it should be noted that few if any non-energy, long-term, capital-intensive projects are being undertaken at this time of high interest rates, business recession and political uncertainty. Novel projects, or those considered to contain untried technology (with attendant real or imaginary risk) are even less likely to be taken commercial. As often stated by the author, prosperity in conjunction with improved metal prices in an era of stability and confidence could rapidly change the future of ocean mining. An additional scenario change leading to early ocean mining could involve a critical requirement for strategic metals, several being found in manganese nodules.

Alternate Cases

None of the alternate cases studied produced returns that can be realistically judged as inspiring or even encouraging. In the reduced scale operation (1.5 million tons/year throughput) the IROR was reduced from 7 to 4.5 percent in spite of the one-third reduction in capital costs. The use of foreign ships and crews (assuming a change in the law or an overseas corporation) improves the IROR almost two points, from 7.05 percent to 8.95 percent. Locating the processing plant at the port produces a fractional improvement in IROR, from 7.05 percent to 7.30 percent. Disposing of the wastes at sea is a break-even if tugs and barges are used and penalizes IROR if the transport ships are made slurry self-unloaders. Regrettably, even combining the alternate cases (crudely) does not raise the IROR to the current prime interest rate.

The alternate cases do show us, however, that a lower cost marine segment (mining and transport ships and crews) is important and can be achieved by use of foreign ships and crews or, more suitably, the judicious use of construction and operating differential subsidies under the 1936 Merchant Marine Act. Also, economies of scale are important to the return, so if we can safely use <u>one</u> mining ship to produce the three million dry tons of nodules (rather than a lesser quantity), there is promise of a better IROR. And, although dumping the wastes at sea does not provide a bonanza, tugs and barges and outfalls hold promise of increased returns.

Sensitivities

It is no surprise that our returns are quite sensitive to metal price variations. If all metals were to increase in price by 25 percent <u>without</u> a corresponding increase in capital and operating costs, after tax IROR will increase from 7.05 percent to almost 11 percent. Similarly, if we assume copper to remain constant, cobalt to gently drop from $20 to $5.50/lb and nickel to strengthen from $3.75 to $4.50/lb over five years, our IROR increases by more than three points to just more than 10 percent. Many consider the second price variation scenario discussed above to be quite realistic, but is hardly the stuff that triggers billion-dollar investments.

After laboring over capital and operating cost estimates for almost two years, the research team was reluctant to acknowledge that capital costs could be overestimated but was quite willing to grant that the complex machinery and equipment in the system could increase in cost more rapidly than metal prices would increase, a basic assumption of this pay-out analysis. Hence, we selected capital costs down by 10 percent and up by 10 percent, 20 percent and 30 percent for this sensitivity test. The IROR varied predictably, improving by 0.65 percent with lower costs, and decreasing by .55, 1.25, and 2.00 percent with higher costs.

The nuclear power industry has taught us the price of delay (and the pain of unanswered prayer), but basic premises of our base case include technical success and no regulatory delays. We selected a one-year and a two-year delay between the completion of the system and earning first revenues in regular production to test the project sensitivity. As we saw in Table 7, the penalty was a decrease of 0.5 percent in after-tax IROR for each year of delay. The result is logical for this model as the time value of money and the "lay-up" costs are included. Extended delays would very likely be more expensive. A positive factor to consider is that the "mine" is not a politically unstable area so alternate geographic plant sites can be selected initially.

Recommendations

Areas for Improvement

Ocean mining profitability and returns can be enhanced by one or more of the following:

1. Higher prices for the metals produced;
2. Lower capital and operating costs;
3. Increased mining and processing efficiency;
4. Tax "breaks;"
5. Production and marketing of manganese and other co-products;
6. Use of foreign ships and crews, or subsidies;
7. Location of the processing plant overseas;
8. Relief from current regulations; and
9. Government funding of R&D and P&E.

Historically, metal prices and plant and machinery costs have advanced or declined in parallel, with metals prices lagging. A basic assumption of the pay-out analysis is that increased operating costs will be offset by higher revenues. Unless these parameters are artifically adjusted by governmental intervention (price-fixing) or market interruption (war or social/political upheaval) this price/cost relationship should continue until terrestrial sources of the metals are near exhaustion. Hence, in the next decade or two, advancing metal prices are not likely to dramatically enhance deep ocean mining returns.

Frequent references to "the learning curve" and the reduction of "computer" prices lack realism in the case of ocean mining. After all, this is a materials-handling problem involving shipping, dredging, ore benefication, and waste disposal rather than an electronics explosion or an aerospace adventure (except in one case) where the technologies tend to be classed "mature." In any developing technology-based undertaking there must be a "learning curve" which tends to reduce capital and operating costs over the life of a process, on the average. We would be more comfortable in the ocean mining area if we were convinced, based on completed R&D and system testing, that we have solved all the serious technical problems and that we have included all the system costs. Increased mining and processing efficiency during the life of this hypothetical project is a certainty -- corresponding reduction of capital and operating costs are much more speculative. These are two most promising long term areas for enhancing profitability and return on investment.

The Economic Recovery Tax Act of 1981 provides significant improvement in the depreciation tax shelter for an ocean mining program with a corresponding increase in internal rate of return. More direct tax "breaks" (domestic percentage depletion allowances, higher investment credits or tax forgiveness) would also enhance this return. Increased awareness of potential strategic metal shortages could serve as the stimulus for this type of indirect government support.

During the mid-1970's, the author frequently testified to the U.S. Congress that a four-product (manganese, nickel, copper and cobalt) ocean mining program was the most likely approach to a rewarding commercial pioneer ocean mining venture. This pay-out analysis is based on a three-product approach, due in part to the insistence of several "metals" companies who have, over a decade, slowly added some manganese to their proposed product line to enhance their return projections. There is a real problem in including manganese as a product -- a single three million dry ton per year project would produce a significant percentage of the U.S. requirement for this metal. More than 90 percent of the manganese produced in the world is used in making steel (as a catalyst or an alloy) providing a most inelastic market. And, although we have included herein revenues from a small quantity of co-products or "secondary" products, the many metals found in the nodules in very small concentrations present an opportunity for the inventive process researcher. The tendency to use "safe" metal winning technology (with attendant royalties) rather than new technology designed to exploit the characteristics of this unique oxide ore is regrettable if significant savings can be achieved in this high-cost area by accepting manageable risks.

All maritime undertakings must consider differences in capital and operating cost between U.S. and foreign "flag" ships. Although European shipbuilding labor costs now approach or exceed U.S. costs, there is an appreciable cost differential between U.S. and Oriental (Taiwan, Japan or Korea) ships built to U.S. standards, including "hidden" subsidies. Provision of construction and operating differential subsidies as provided by the 1936 Merchant Marine Act (as amended) could be employed to achieve these same savings. Additional reductions in crew costs result from reduced manning requirements and fewer fringes. This "un-American" approach may prove to be impractical for the mining ship due to its inherent "high technology" content but promises to be quite rewarding for the nodule transports. Similarly, location of the processing plant in a stable low cost nation could improve the returns.

In a similar vein, relaxation of existing U.S. regulations, such as ship-manning (USCG), safety (USCG and OSHA), pollution (EPA or perhaps NOAA regulations under Pub. L. 96-283) and others, promises to reduce both capital and operating costs. The insurance industry (through rate setting) and the critical need for uninterrupted production should preclude unsafe practices at sea and ashore with system efficiency and reduction of delays and paperwork providing the rewards. Certainly.

relaxation of current antitrust laws could reduce the cost of entering the industry.

During the UNCLOS debate (pre-Reagan) when "technology transfer" seemed inevitable, certain technology firms suggested government funding of the R&D and P&E efforts to assure their continuation in the absence of commercial incentives. Industry sympathy was limited to those who would rather work for the government than not work at all. The present administration in Washington seems to have reduced this alternate to the more constructive level of guiding the regulatory and tax regimes from punitive to "hands-off" to supportive. This situation is clearly helpful -- its endurance for the life of the project would positively influence the returns.

Clearly, no single improvement discussed above is a "fix" for the discouraging returns forecast in this pay-out analysis. Partial achievement of several, however, could appreciably improve the project's returns.

Use of This Pay-Out Analysis

The basic purpose of the research reported upon herein is to define and price a complete functional deep ocean mining system and to prepare a pay-out method to evaluate the impact of changing the system's major parameters, including the capital and operating costs of the regulatory regime required by the 1980 Ocean Mining Law. As previously discussed, defining the system and estimating cost were major efforts. Our reluctance to use historic costs and "factors" in the novel sectors of the system resulted in a "real system" with well-documented costs for this particular system, but does limit the application of this work. The sponsor and these researchers accept these limitations. We strongly suggest that the user consider the estimating methods and results before he reduces this work to parametric prices or dimensionless coefficients for "general" use. A population statistic of 2.7 children may be useful, but 3.5 ships gives Archimedes and most naval architects deep chills. The estimating effort in our ore-mining ship, two transport ship alternate case brought this fact home to us. On the other hand, the pay-out model is quite general and can handle wide variations in numerical inputs. Our admonition is on the quality (accuracy) of the input data.

Although a simplified pay-out model is most often used to compare projects, it is essential to preserve the accuracy of the results by not oversimplifying the model. Under the pre-1981 tax law, the long depreciation lives of much of the plant and equipment made the use of accelerated depreciation essential to achieve a realistic return. On the other hand, the 1981 tax law with its five-year plant and equipment lives provides adequate tax shelters (in this study) to eliminate corporate income taxes for the initial seven years of production.

The model now includes a percent of revenue payment into an escrow fund, as required by Pub. L. 96-283, but still omits depletion allowances. On the other hand, the author has assumed that future ocean mining project managers will be able to convince the Treasury Department that they should receive tax-loss-carry-forward benefits for costs incurred during the construction period (six years) prior to generating revenues. Mr. Gardener Symonds, the founder and chairman of Tenneco until his death, advised the author to "leave a little for the accountants to offset the costs you overlooked and to encourage them to support the project." We believe that the factors included are clearly identified in the base case print-out and Appendix B while recognizing that the reader/user may question our selections. Used with care, the model should provide worthwhile guidance to a prudent professional in evaluating his interest in this developing natural resource opportunity.

Continuing Effort

The author has consistently contended that early deep ocean mining programs will depend upon effectively marketing some, or all, of the manganese content of the nodules. After all, 25-35 percent of mine grade nodules is manganese, and although this metal is priced lower than nickel, copper and cobalt and raises potentially severe marketing problems, it must be considered an opportunity in view of the politically sensitive sources of terrestrial supplies and its strategic importance to our nation. Hence, we would recommend that our continuing effort address the subject by undertaking the following studies:

1. Prepare a scenario and define a mining, transportation, processing and waste disposal system for two million dry tons per year of manganese nodules yielding four products: manganese, nickel, copper and cobalt.
2. Estimate the capital and operating costs of the system in 1982 U.S. dollars.
3. Analyze the returns from the two million ton, four-product system under the 1981 Tax Law examining:
   - (a) A base case;
   - (b) Alternate forms of project organization;
   - (c) Alternate percentages of debt and equity;
   - (d) Tax-free bond financing;
   - (e) Various depletion schedules; and
   - (f) An optimum mix of the above parameters.

4. Modify the Texas A&M pay-out model to permit the above analyses.
5. Regardless of the throughput level or the products produced, our work has clearly indicated the significance of the cost of energy on the returns from a Deep Ocean Mining project. Hence, we recommend that the sensitivity of nodule processing costs to fuel/energy alternates be investigated and that trade-off analyses be made to optimize energy usage for both three- and four-metal systems.
6. In this report we have assumed the capital and operating costs of regulation to be zero and, even though reasonable regulations will not result in significant erosion of returns, we are now in a position to estimate these costs with some confidence. The earlier work by this researcher [3] and the preliminary/partial results of NOAA's current research effort suggest that we can now hypothesize a system and estimate capital and operating costs for a deep ocean mining and at-sea waste disposal environmental monitoring system for use during system tests and full-production operation.

REFERENCES

1. Nyhart, J.D., et al., "A Cost Model of Deep Ocean Mining and Associated Regulatory Issues," Mass. Inst. of Technology, Cambridge, Mass., March 1978.
2. Dames and Moore and EIC Corporation, "Description of Manganese Nodule Processing Activities for Environmental Studies, Vol. III; Processing Systems Technical Analyses," Chap. 5, Boston, Mass., August 1977.
3. Flipse, John E., "The Potential Cost of Deep Ocean Mining Environmental Regulation," Texas A&M University, Sea Grant College Program Publication TAMU-SG-80-205, College Station, Texas, July 1980.

APPENDIX A

TOWARD DEEP OCEAN MINING IN THE NINETIES

A Description of the Preproduction and Commercial Stages of a Hypothetical Pioneer Venture

by

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Project No. R/MO-2
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At the time the research was in progress:

James M. Averback was a research assistant in the Ocean Engineering Department at MIT.

Michael A. Gillia was a research assistant in the Ocean Engineering Department at MIT.

RELATED SEA GRANT REPORTS

Nyhart, J. D., Lance Antrim, Arthur E. Capstaff, Alison D. Kohler, and Dale Leshaw. A COST MODEL OF DEEP OCEAN MINING AND ASSOCIATED REGULATORY ISSUES. MITSG 78-4. Cambridge: Massachusetts Institute of Technology, 1978. 240 pp. $10.00.

MIT/Marine Industry Collegium. DEEP OCEAN MINING: A COMPUTER MODEL FOR INVESTIGATING COSTS, RATES OF RETURN, AND ECONOMIC IMPLICATIONS OF SOME POLICY OPTIONS: OPPORTUNITY BRIEF #12. MITSG 78-12. Cambridge: Massachusetts Institute of Technology, 1978. 26 pp. $3.00.

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TABLE OF CONTENTS

I. Introduction and Overview

The intent of this paper is to provide a narrative describing the projected major events for a hypothetical pioneer deep ocean mining project involved in the mining of manganese nodules. It is part of a follow-on study by a team at MIT which provided an initial estimate of costs of such a project (Nyhart et al., "A Cost Model of Deep Ocean Mining and Associated Regulatory Issues", MIT Sea Grant Program, MITSG 78-4, March 1978). The MIT project team has over the past two years collaborated with three consultants under contract to the Office of Ocean Minerals and Energy, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The consultants are: Benjamin V. Andrews, Manalytics, Inc.; Francis C. Brown, EIC; John E. Flipse, Texas A&M University. Each has submitted cost estimations to NOAA covering one or more of the three major technical sectors --ore transportation, processing, and mining. The consultants, NOAA's Office of Ocean Minerals and Energy, and the project team collaborated over many months to arrive at a consensus as to what a reasonable scenario of events might be for cost modelling and analysis purposes as a typical pioneer venture moves from its present state to commercial production. This description of events constitutes the body of this paper.

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 partner or by an organization formed for that purpose. This consortium is assumed to be based in the United States, with processing facilities located in the United States. The manganese nodules are assumed to be 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 from Mexico to 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. In this study, the processing plant for illustrative purposes is assumed to be on the West Coast of the U.S.

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 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 will supply the information necessary to make a decision as to 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 has committed 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 project begins at the completion of construction of the capital equipment for the mining, transportation and processing activities and the start-up period, estimated to require between one and two years. During the start-up period the technology is further debugged and the system is brought up to its full design production rate. The project will operate at this design capacity through the remainder of its life (approximately 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 assumed to be 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 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 efficiencies are improved. The data required for this redesign effort will be generated, for the first time, from the actual commercial operation itself. Likely improvements will be 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 will provide the miner with a complete and accurate topographic and assay map of the site. Also, a mining plan will be developed, keeping at least one year ahead of the mineship operation. Finally, low-level service from the assay lab will be 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 will have a configuration similar to that of a drillship, with a central moon pool, a gimballed and heave-compensated pipe suspension system and pipe handling equipment. Provisions will be made for the stowage of mined nodules which will be periodically off-loaded at sea to a transport vessel. The mineship will be 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.-6. Marine Transportation, Ore Discharge Terminal, Marine Support Operations and On-Shore Transportation

The transportation requirements include 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 located on the West Coast of the United States, requires a fleet of ore transport vessels to interface with the mineship(s), a dedicated terminal 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. Providing the mineship(s) with fresh crew and supplies will be accomplished by use of both the transport ships described above, and a high-speed supply vessel which may be based at a second port facility located nearer the minesite (possibly in Hawaii). This alternate port facility will serve as a logistics base for the mineship(s) and its supporting vessels, and for the research vessel(s). The removal of wastes from the plant to a land waste disposal site will be via a slurry pipeline system. If the wastes are to be disposed of by ocean dumping, the nodule slurry pipeline will be used to deliver waste to the port facility. If an ocean outfall is used, a separate pipeline will run from the plant to an authorized discharge point. Also, provisions for roads and/or rail spur lines to transport personnel, supplies and products to and from the various facilities mentioned above, must be made where necessary.

7. Processing

The recovered nodules are assumed to be processed using an 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 assumed to be located on the West Coast of the United States, thus allowing easy access to the anticipated minesite. Siting of the plant is assumed to be 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 should be built as close to the ore discharge terminal as is economically and politically feasible.

8. Waste Disposal

This analysis assumes that the tailings waste will be disposed of by using lined slurry ponds at a site remote 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 pre-treatment. The use of ocean dumping or an ocean outfall are other disposal alternatives which might be considered.

Section II contains a more detailed description of the above phases.

II. Detailed Description of Events

A. Pre-Production Phase

Each consortium participant which considers ocean mining as a feasible project will probably have a "Long Range Planning" capability in the form of 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. It is the function of this capability to decide how, if at all, the project will proceed and to allocate 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 a "GO1", "GO2", etc.) can be considered as "off-ramps" which are encountered at the end of one step and prior to the funding and commencement of the next. If the project evaluation conducted upon completion of one stage proves the project worthy of further investigation, the planning entity then allocates funding, probably at an increased level, for the next stage of work. If the project does not appear favorable, the decision to take the off-ramp could be made, thus resulting in shelving (a delay) or termination of the project. The P&E and R&D work conducted during the "up front" phase of the project establishes a bank of knowledge upon which the consortium entity will base the ultimate decision to go, or not to go, into the investment phase, and hence into commercial production. This ultimate decision will be 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.

1. Pre-Commercial-Mining Prospecting and Exploration

Prospecting and exploration activities are carried out in two phases. The first, or pre-commercial-mining phase, is a continuum of activity during which the miner delineates a minesite based on ore abundance, ore grade, soil characteristics and topography. The second phase, called continuing P&E in this paper, 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 done in the first phase. This second, continuing P&E is discussed further in section II-C.

Pre-commercial-mining P&E can usefully be described as comprising the following three stages.

a) Background Work

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

b) 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, further narrowing the sections for future surveying. Here, the above experience suggests an area of approximately 126,000 square nautical miles is sampled using free-fall grabs and still photographs, with the possibility of using 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.[2]

c) Exploration

The objects 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 selected area is searched with photographs and seismic surveys. Extensive sampling and bathymetric measurements are taken. As an illustration, an area of approximately 8,000 square nautical miles is surveyed, utilizing free-fall grabs, still photos, a dredge for bulk samples, spade and/or box cores. Bathymetric and seismic measurements are also made.

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

During these activities, a mining plan will be established which is capable of guiding the mining operation. Upon completion of these activities, the mining plan must be sufficiently developed so that mining operations can begin. Costs during this P&E period are composed of vessel charter rates, research team salaries and other costs such as navigation, sampling and surveying equipment.

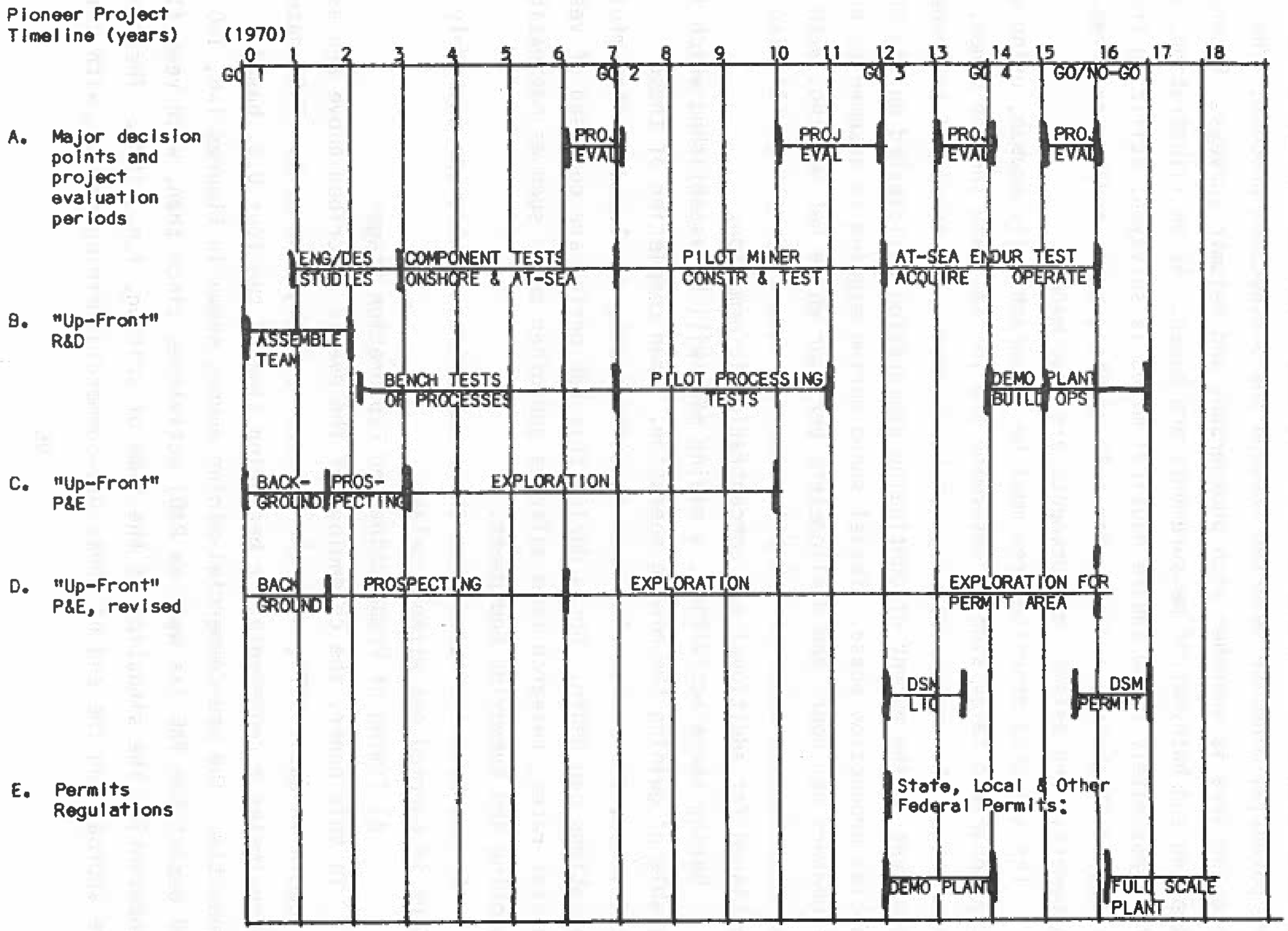
It has been estimated that these activities require approximately seven years if carried out without delay.

d) Timing of Prospecting and Exploration Stages

In this paper, the chronology of the events described above are assumed to begin in about 1970, with the one year's background work. This date approximates a representative beginning time of the four U.S. based consortia. The pre-commercial-mining events shown in Figures 1-B, 1-C and 1-D depict the P&E (as well as R&D) activities since then, 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

Figure 1 A, B, C, D, E:

Timing of "Up-Front" Phase for a Pioneer Project



R&D at-sea endurance and demonstration work remaining before a final go/no-go decision is taken.

That consortia experience is "living history" is demonstrated by a comparison of Figures 1-C and 1-D. Figure 1-C was developed during early 1980, and took the perspective of a mining project manager at the outset, i.e., year 1, assuming also that interim U.S. legislation had then been enacted. (See Lane and Jugel, Note 2) Figure 1-D shows the more realistic situation existing after U.S. legislation was actually passed in mid-1980, adjusted to show pre-commercial-mining extending to just prior to application for the permit required by the new U.S. legislation, i.e. by year 15. Figures 1-B and 1-D also incorporate delays reflecting the impact of industry project evaluations of the economic, political and international legal climate, (see below). The net effect is that the continuing of P&E activity is likely to stretch over 15 rather than 10 years as projected in Figure 1-C, though at a diminished level of annual activity.

2. Pre-Commercial-Mining Research and Development

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

Pre-commercial-mining R&D is further subdivided into two stages. In the initial stage, the current technical status of ocean mining and the potential for future financial returns are ascertained. These goals are accomplished 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 knowledge, an initial marketing strategy and business plan are developed. The marketing strategy will define 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, tradeoffs between metal market and technical considerations must be made. The business plan will delineate a detailed program, schedule and budget for the next, or major, R&D effort and set forth a tentative plan for commercialization activities, including capital funding. This business plan will be dynamic in nature, undergoing an evolutionary process as more knowledge is gained through R&D activities.

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

In processing R&D, both a pilot plant and a demonstration plant must be designed, built and operated. The pilot plant will be about a 1/10,000 scale operation whose key objectives include: the demonstration of the process concept in an integrated plant; the acquisition of preliminary design data for key operations; the determination of materials consumption, produce yields and product purities; and process revisions/optimization studies as required. In addition, the pilot plant would also provide information for cost estimates for both demonstration and commercial plants.[3] The demonstration plant will be about a 1/20 scale, "green field" operation.

From the demonstration plant will come the final design data for the commercial processing plant. It may also be beneficial to determine the siting requirements of the commercial plant at this step, since the closer the demonstration plant is sited to the commercial plant, the better.

Transport R&D must deal 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 must deal 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 are a substantial part of the overall capital requirements of the project. The greatest portion of funding is required for the capital-intensive processing pilot and demonstration plant tests and the mining system demonstration scale test.

a) Timing

The beginning of the initial pre-mining R&D step is signified by the first "go" decision (G01) as shown in Figure 1. This "go" decision results in the allocation of funds for the preliminary R&D work. As in the case of

P&E, this work is assumed to have started during 1970, the initial year of the project. This initial effort is conducted at low levels over a seven-year period (see Figures 1-A and 1-B). Following this period, and assuming some technical success, a second "go" decision is made in year 7. One consideration during the evaluation period preceding 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 of these activities are the design, development and initial testing of the pilot mining system at sea and the pilot processing plant on land. These are assumed to 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, generally believed to have already completed most of their pilot work.

A third "go" decision point is reached before at-sea endurance testing is begun and is projected for the beginning of year 12 (or 1982). It marks the beginning of the most expensive R&D work. The project evaluation period preceding it is rather long, because of the higher expected costs of the endurance tests and demonstration scale processing plant (which follows), and the economic uncertainties and those currently surrounding the Law of the Sea negotiations. The actual year of this decision point will depend 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 must precede the decision to begin construction. The timing of the demonstration plant permitting period is illustrated in Figure 1.

For this analysis, it is assumed that by the sixth month of at-sea endurance testing, the required demonstration plant permits are in-hand and technical success with the mining system is sufficient to allow for the construction of the demonstration scale processing plant to begin. At this point, a fourth "go" decision, to commit to building the demonstration plant, is shown, reflecting the possibility that consortia management are using short planning horizons in light of the uncertainties to which reference has already been made. A tightly scheduled one-year construction period is shown on the assumption that not all demonstration plant sub-systems must necessarily be in place for testing to begin. During the demonstration plant construction period, at-sea endurance testing and consequent nodule stockpiling activities are continued 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, the demonstration plant operation period commences. This run is assumed to last for two years.

Halfway through this period, at the beginning of year 16 (or 1986), the decision of whether or not to invest in a commercial size project is made. This decision is based on all of the information gathered up until that time, 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 1). The extra year of demonstration plant operation, after the final "go", is used to provide additional data for use in the design and operation of the full-scale plant.

b. Impact of U.S. Federal Law on Timing

It is assumed that the hypothetical operating entity is United States based and therefore subject to the U.S. Deep Seabed Hard Minerals Resource Act (P.L. 96-283), which regulates the conditions under which United States based entities must operate when mining the deep seabed. The Act requires that a U.S. deep ocean miner 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. Because U.S. interim legislation was enacted only in mid-1980, license applications of the existing consortia are not expected to be submitted until early 1982, or year 12 in Figure 1-E. 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. Halfway through year 15 (1985), application will be made for a DSM permit. The consortium should therefore have a DSM permit one year after the "go/no-go" decision.

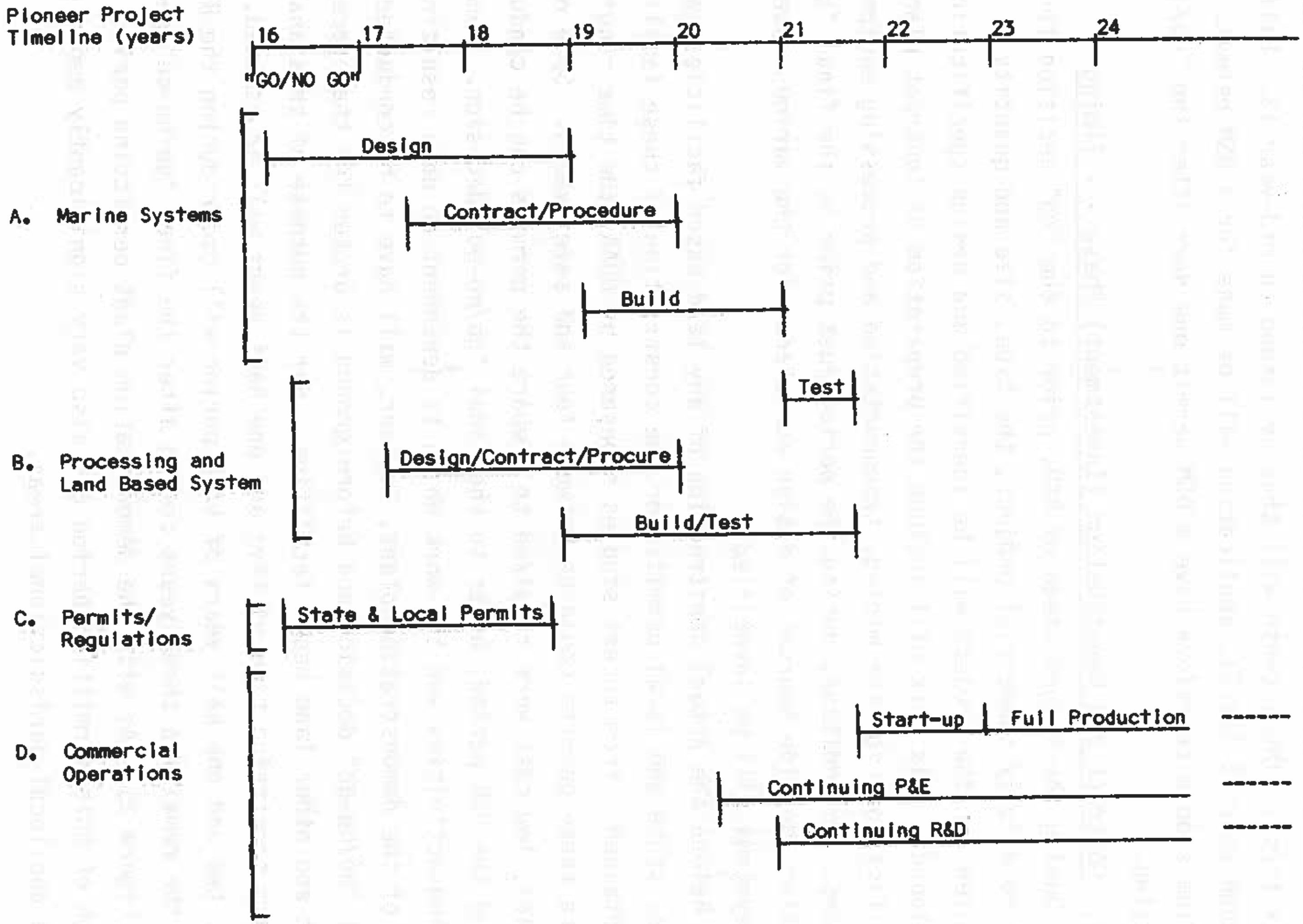
B. Contract and Construction (Investment) Phase - - Timing

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 will be identified and design specifications developed. This work will include 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 sytems and sub-systems will be identified.

Before the actual construction of any land based facilities can be begun, 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 and the 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 one half years will be assumed. The first two and one half years of this period will occur during the R&D period with the remaining three years coming after the final "go/no-go" decision (see Figure 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.

Figure 2 A, B, C, D:

Timing of "Contract and Construction and "Commercial Operations" Phases



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 building or fabrication effort. In addition, there may also be a testing program initiated upon completion of the building activities.

With the final "go" decision, the various system design efforts will begin. This work will concentrate on confirming and correcting contract specifications, developing sub-systems 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 will supervise and integrate these design efforts.

The contract and procurement activities will 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 actual building effort begins. It is during this period of building that the most significant expenditure for the major capital cost systems will be made.

The timing of these allocations may vary from sector to sector. Figure 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 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).

From Figure 2, it can be seen 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 assumed to be 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 is taken to start one year and six months into this phase, during year 17 (1987) of the project timeline. This final design effort continues through year 18 (1988) of the project timeline, with extensions into year 19 (1989) for the dredge pipeline and collector systems. The contract and procurement activities, with the exception of those mentioned above, begin in year 17 of this phase and proceed 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 (1990). A six-month testing period is begun at the outset of year 21 of the project timeline. The purpose of this testing period is to allow 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 phases for the commercial processing plant begins a year after the "go/no-go" decision and finishes four and one 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 three and one half years of this phase. The actual construction begins two years into this same 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 schedule similar to that described above and for the processing plant. (See Figure 2.)

C. Commercial Production

As described in the introduction, there are interdependent operations involved in the commercial operations phase of a deep ocean mining project. They include the continuing P&E and continuing R&D activities; the mining, ore transportation, and processing operations; the crew and supply vessel operations; on shore transportation to and from processing plant; the operation of the marine terminal facility; and the waste disposal efforts.

1. Continuing R & D and Prospecting and Exploration

During the mining operation, a complete and accurate topographic mapping must be accomplished using side-scan sonar, television, etc. In addition, a seafloor 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.

The operation will be 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. Thus, staff requirements will consist of 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. Mining

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 task, two specially constructed mining vessels will be required to collect the 4,500,000 tons of wet nodules. Two vessels also should prevent a total shut down, should one vessel be disabled. The number of mineships employed will be based on both engineering and financial criteria. The engineering criteria are 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 associated with a one-miner system versus the back-up capabilities afforded by a multiple mineship operation. If engineering analyses show that a single miner operation is feasible, a financial analysis must be conducted to evaluate the relative monetary implications of the catastrophic loss of a mineship for a one-miner 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 will be assumed that the mineships are U.S. built vessels whose design configuration will be a combination of an ore carrier and a drill ship. The vessel will be required to stow large quantities of nodules in addition to supporting significant amounts of mining machinery and crew facilities. There must also be appreciable capacity allotted for the stowage of spare parts, fuel oil and food. Special features, similar to those found on various drilling ships, include a sizeable moonpool through which the mining pipestring will be suspended, a large motion-compensated derrick with associated draw works for supporting the pipestring, racks for pipe storage and dynamic positioning equipment for keeping the vessel on course while mining.

The ocean mining operation itself entails the removal of the manganese nodules from the ocean floor and the subsequent lifting of these nodules to the surface. The operations will be accomplished through the use of a towed bottom collector unit equipped with steering capability and a hydraulic lifting system. The collector unit will be gathering the nodules, sorting out those that are too large for the selected pipe diameter and feeding the acceptable ones to the lift system for transportation to the surface.

The system that is proposed to accomplish the task of conveying 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 pipestring (dredge pipe). There are basically two designs that are being considered for the first generation lift system: conventional slurry pumps and an airlift system. The slurry pump system uses submerged, multistage centrifugal pumps to lift the mixture to the surface, while the airlift system injects air into the slurry to reduce its density so that a three-phase mixture of air, nodules and water is lifted to the surface. In this description the slurry pump design is assumed.

The equipment groupings for the mining operation include Equipment and Supplies Handling, Nodule Pumping System, Dredge Pipeline, Collector Unit, Ore Handling, and the Mineship Main Structure.

The Equipment and Supplies Handling sub-sector should provide for one or two cranes aboard the miner for handling the mining equipment, loading supplies and handling the fuel and nodules umbilical. A small, seaworthy launch should be available for picking up air-drop bundles as well as handling lines, clean-up gear and man-overboard duties. A floating fuel and nodules umbilical must be provided to facilitate at-sea transfer operations. A motion-compensated pipe suspension tower with adjacent pipe rack and skidway are necessary. Deck-mounted reels for handling the power cable must also be located adjacent to the pipe suspension tower.

The nodule pumping system sub-sector must take into consideration the following items. Pumps for supplying the lift power for raising the nodules will be necessary. Power cable and related connectors for the submerged pump system will be required for providing power to the pumping unit and to the collector unit. Provisions must also be made for in situ instrumentation and topside controls for the lift systems. Also, dump and diffusion valves for the lift system must be considered.

The dredge pipeline system will require the following items. The individual pipe sections of the lift (dredge) pipestring, whose length can be selected based on the ship and pipe suspension tower configuration, with larger lengths resulting in savings in coupling units and deployment time. 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 is described.

The items included in the pumping system, the dredge pipeline system and the collector unit itself will have 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 should have provisions for four items: equipment for interfacing the mineship and the pipestring, thus allowing for the transfer of nodules between the two units; 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 finally, a slurry self-unloading system for transferring the nodules from the mineship holds to the transport vessels.

The mineship will be sub-sectored into the hull structure group, the hull engineering components, the outfit, 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 will be a diesel electric plant which will utilize several diesel engines to drive generators. The generator output, in turn, could 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 also be developed to allow the miner to follow a pre-determined mining path. This system will most likely include electronic navigation equipment for position finding, bow and stern thrusters for position keeping and an electro-mechanical servo-control system for interfacing the electronics and the propulsion and ship control equipment.

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

Except for the maintenance and repair (M&R) of the ship and mining equipment, mining will proceed around the clock for the balance of the year (weather permitting). One full-time ship and mining crew will 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 hours-on, 12-hours-off work days and rewarding salaries as well as comfortable on-the-job working and recreational surroundings.

3. Marine Transport

The transportation of nodules from the mineship to the ore discharge terminal will be via a fleet of equal sized bulk ore carriers. There will be at least two of these transport ships provided in the system to minimize vulnerability to total stoppage. Their size and number will be governed by draft restrictions in the dedicated port (and other ports of call), the distance from the minesite to that port, the nodules 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 will be 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 to be designed to carry a dewatered slurry of whole nodules. These vessels will be 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 will be hopper shaped, with smooth sides, to expedite cargo removal. Slurry water in these holds will be decanted for stability purposes.

Fuel for the miner will be 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 fuel. 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 will be conducted during the R&D period.

When the ore transport vessel reaches the port facility, the nodules will be removed from holds by portable, dock-side slurry units. However, as an alternative, the ore carriers can be fitted with their own internal unloading system. Such a system would be similar to that employed by the mineship. Water jets located in each hold of the vessel would be directed into the stowed nodules, thus slurrying the ore which would then flow to a collecting pump under each hold. Slurry water is then 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, it is possible that slurry discharge ships could be used. This option would result in the use of larger slurry transport ships in combination with disposal barges for handling the excess wastes. The larger transport size would result from the extension of port time for these vessels due to the loading of outbound tailings for disposal. The waste slurry would be 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. The assumption here is that permits for the discharge of wastes at sea would be obtainable.

4. Ore Discharge Terminal

An ore discharge terminal facility will be developed in a deepwater port assumed for illustrative purposes to be on the West Coast of the United States. This facility will serve 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 will be loaded onto the ore carriers for the return trip to the miner. Also, if the ocean dumping of process tailings is required, the vessels which dump the wastes (ore carriers and barges) will be loaded at this facility.

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 will be the limiting factor in the design of the ore carriers. 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 will be assumed to be about 25 miles (mid-range) as a central value.

The ore discharge terminal facility is assumed to require 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. In addition, there will be provisions for utilities, sewerage, storm drainage, fencing, parking and other site services. The building structures at the port will be minimal and will 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 must be provided for mooring the ore ships. Probably only one dock facility will be 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 be made to determine whether it is more practical, from a financial standpoint, to build a new dock facility or to slow down the transport vessels, thus resulting in some increase in size and/or number of required vessels. The pier must be strong enough to support several moveable cranes mounted on a rail system (one for each hold of the transport vessel). These cranes will suspend the portable slurry discharge units to unload the ore transport vessels. The berth for these vessels must provide a water depth larger than the loaded draft of the vessels. This depth will be provided by dredging if necessary. In addition, 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 will be designed to unload the ore carriers in under 24 hours so as to facilitate quick turn-around of the ore carrier. The nodules will be discharged into a nodule storage pond at the port facility. This pond will be large enough to handle at least two shiploads of nodules, so as to allow surge capacity if the port-to-plant pipeline should be out of service temporarily. The slurry discharge units will utilize a closed loop water system; therefore, a contaminated salt water recycling tank of very large capacity is required. 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 could include either one or more pipelines from a remote source in the port or on-premise tankage. In both cases, however, additional piping and pumps will be required to load the transport vessel.

An alternate method of bunkering could be via 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 assumed to be powered by diesel engines; thus both vessels require diesel fuel.

Power for the port facility is assumed to be provided from the grids of local power companies. The major power consumption will be for the unloading of the nodule carriers and for the pumping of the nodule slurry from the terminal to the processing plant facility. (The nodule pipeline and its related equipment will be discussed in sub-section 6 below.)

If ocean dumping of process wastes is chosen as a viable disposal technique, the terminal facility must be expanded to allow for receiving this waste and loading it onto the disposal vessels. This operation will require 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 which allows for 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.

For tailings loading onto the transport ships and barges, a substantial pumping system would be installed to achieve rapid loading. Several thousand kilowatts of electric power would be needed. This power requirement could be several times larger than 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 at the terminal facility, if the power utility company could not meet the increased demand.

5. Marine Support: Crew and Supply Vessel and Alternate Port Facility

A small, fast ship will be available (through purchase or charter) to transport crew and service personnel between the mineship(s) and a logistics base ashore. This vessel will also handle mail, films, spare parts, food and supplies for the miners. The supply vessel should provide hotel accommodations adequate for the crew replenishment task. The number of crewmen handled per trip is a function of the frequency of calls the vessel will make 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 will be equipped with a small, medium range, heavy lift helicopter and associated helicopter pad for emergency transfer of people and equipment to the miner. In addition, 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 will be stored at the logistics base when not in use.

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

The land requirements for the logistics base are not excessive. Provisions should be made for enough acreage to support a P&E lab and storage facility, a parts warehouse and supplies logistics 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 procurement of this facility would probably involve a leasing arrangement where the terminal facility requires little or no site preparation and has all utilities already in place. The only major capital expenditures would 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.

6. <u>On-Shore Transportation</u>

a. Port to Process Plant Slurry Pipeline

Transportation of the manganese nodules to the process plant will be via slurry pipeline system with slurry water being recycled to the port facility. The system will require both slurry and decant piping, slurry and decant pumps, a slurry water storage tank(s) and right-of-way land for the pipelines. There will also be enough slurry water storage provided at the port facility for start-up procedures. The pipelines will be buried only if required by local ordinances.

b) Waste Slurry Pipeline

The disposal of process wastes by slurry disposal ponds will require the use of a waste slurry pipeline system. This pipeline is very similar to the nodules slurry pipeline system. The system will be a closed loop system with slurry water being recycled to the process plant for reuse. The system will require 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 will be steel units with pumping and recycle water storage facilities located at the process plant.

c) Roads and Railways

The transportation of supplies, products and personnel to and from the process plant and waste disposal site will necessitate the 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 will require both rail and road services due to the large volumes of supplies and products which must be handled. The location of the process plant will be assumed to be within five to ten miles of a major rail line, thus a rail spur of this length will be required. In addition, access roads connecting with a major thoroughfare are required. These roads must be capable of handling frequent heavy trucking and therefore must be of a substantial nature. The waste disposal facility will also require access roads capable of supporting heavy trucking.

Both the access roads and the rail spur line will require the purchase of right-of-way land. This land will require survey and land preparation operations before pavement or tracking can be installed.

7. Processing

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. 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, combined with drying in fluid-bed dryers. Entrained nodule fines are removed from dryer off-gases with cyclones and electrostatic precipitator 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 the dust. In the extraction steps, the nodules are quenched in 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 Metal 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 the necessary tankage and 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 state 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 commercials 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 are 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 for illustrative purposes 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.

Operations within the plant will be on a three-shift, 24-hour day, 365-day/year basis. Down times for maintenance and repairs will result in a full production schedule equivalent to 330 days per year. The plant will employ about 500 people including operating, maintenance, supervision, general plant and administrative personnel.

Additional treatment of tailings from the process plant may be required before disposal. This treatment could involve the precipitation of toxic elements or a combination of this procedure plus washing of the solids. These operations require substantial amounts of additional equipment and operating supplies. For central values analysis purposes, these options will not be considered. However, they do represent add-on options for future analysis.

8. Waste Disposal Site Considerations

The disposal of processwastes, by slurry ponds, will require the use of a waste slurry pipeline system. The disposal of the slurred tailings will be assumed to be in impermeable slurry tailings ponds. These tailings ponds will be 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 will probably be less than 100 miles.

Essentially, this tailings disposal method consists of earth embankments, behind which waste materials are deposited in slurry form. The embankment can be either a total enclosure or it can be a cross valley or side hill type. For this analysis the total enclosure technique is employed. The tailings are transported to the disposal area in a slurry pipeline and are deposited into the reservoir through a series of distribution pipes and spigots. Excess transport water will be decanted off the slurry ponds and recycled to the plant for reuse. The design of the tailings embankment has to be such that it is stable under static and dynamic loading conditions and is capable of handling design floods. It must also be designed so that seepage is controlled through the embankment, using impermeable synthetic liners and/or impermeable clay liners.

The tailings ponds will be about 40 feet deep. For one year wastes from a three-metal plant, a tailings pond of about 65 acres is required. However, this size can vary depending on the local evaporation rate at the waste site and the density to which the slurry will settle. Based on the above figure, the total waste disposal land usage for a 25-year project is about 1,700 acres.

Construction of all the tailings ponds required to handle the wastes will not be undertaken at one time, thus reducing the initial capital expenditures. Initially ponds will be prepared capable of handling the first three years of operations. In the second and subsequent years additional ponds will be added on an annual basis, so that a two year capacity will be at all times available.

The first step in the construction of these ponds includes the stripping and stocking of topsoil for later use in revegetation. Following this, an impermeable bed is developed using a synthetic liner. If the waste site is located such that the underlying soil or rock is relatively impermeable, this step is not required. The tailings embankments will be constructed in stages with materials borrowed from inside the disposal area, if possible. 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 located 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.

III. Summary

The timing of a deep ocean mining operation can be broken down into three phases. Phase 1 involves the "up-front" operation which includes R&D and P&E activities. These activities are conducted in parallel and at varying levels of intensity.

Phase 2 of the operation begins with the affirmative decision to proceed with commercial activities, known here as the final "go/no-go" decision. Phase 2, or the Contract and Construction (investment) phase of the operation, involves the final detailed design work, contract and procurement activities and the actual construction activities for the project. It is during this phase that the majority of the capital expenditures for the project are allocated.

Phase 3, the Commercial Operations phase of the project, includes the start-up period, during which the systems are brought up to full capacity, and the full production period, during which the system operates at or near its design capacity. Continuing R&D and P&E activities are also conducted during this phase.

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 (Figures 1 and 2) which summarize the overall timing of a venture. At the time of writing, 1981, the U.S. based consortia are understood to be at the point roughly corresponding to year 11 in the timelines. The time prior to year 10 is past history. It is assumed that the pre-mining P&E, bench test R&D, pilot miner construction and testing are completed or nearly so and that 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. It is assumed that 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 periods (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 will enter 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 will require five and one half years as explained in section II-B.

After about one year of additional design work, orders will start being placed for major equipment. Plant construction itself cannot begin until state and local permits have been obtained, about mid-year 19. Thus the whole phase lasts about four and one half years.

The Commercial Production period will begin halfway into year 21 with start-up lasting one and one half years for both mining and processing. Thus, at the beginning of year 23 full production will begin and run for about 20-24 more years.

NOTES

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," in Managing Natural Ocean Resources, II Ocean Policy Studies 1, 31. Center for Ocean Law and Development, U. Va. Law School 1979.

3. That is, a wholly new plant, built from the ground up.

APPENDIX B

DEEP OCEAN MINING PAYOUT

An analysis to determine the effects,
if any, of the regulatory regime to
be established by Public Law 96-283,
the "Deep Seabed Hard Mineral Resources
Act" on the profit and returns, if any,
of a pioneer deep ocean mining venture.

by

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31 December 1981

SUMMARY - DEEP OCEAN MINING PAYOUT

Date of this analysis 31 Dec 1981

METHOD: Mining System - 2 mining ships, in-line pumps, 3 transports.

Processing - Reduction/Amonia leach, plant remote from port, evaporation pond waste disposal, West Coast, USA.

MINE LOCATION: In near-Clarion/Clipperton fracture zone, 1700 miles from port.

ANNUAL MINING RATE: 4,500,000 short tons, wet
3,000,000 short tons, dry

Analysis
(amounts in thousands of 1980 dollars)

Funding	
Capital	
Sectors 1 thru 8	$ 1,021,200
Sector 9	-0-
Write-offs (Construction Period)	126,000
Working Capital(1)	175,000
Preparatory Period Expenditures(2)	172,000
TOTAL	$ 1,494,400
Depreciation (Straightline)	
Sectors 1 thru 8 (adjusted for salvage)	$ 49,200
Allocation of Write-Offs(2)	8,600
TOTAL	$ 57,800

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(1) Recovered (plus 10% equipment and building salvage value at $101,000) and land at cost at end of project.

(2) Preparatory Period Expenditures may be considered a sunk cost, with no write-off.

Annual Sales & Revenue	
Products (Ni, Co, Cu)	$ 410,300
Secondary Products (3%)	12,300
	$ 422,600
Less: Product Transportation(1)	4,200
Payments to Escrow Fund	3,170
NET	$ 415,230
Annual Operating Costs (including depreciation)	
Sectors 1 thru 8 inclusive	$ 228,600
Sector 9(2)	-0-
Straight-line Book Depreciation (adjusted for salvage)	49,200
SUB-TOTAL	$ 277,800
Allocation of Write-Offs (Preparatory Period)	8,600
TOTAL	$ 286,400
Profit Before Taxes	$ 177,900
Return on Total Funding	8.61 %
Return on Fixed Capital	12.6 %
Payback Period	19 yrs 4 mos
Discounted Cash Flow Return (26 year project life)	8.50 %
Profit After Taxes	$ 96,100
Payback Period	26 yrs 0 mos
Discounted Cash Flow Return (26 year project life)	7.05 %

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(1) From plant (West Coast) to freight equalization points (mid-west or East Coast) at 1% of gross revenue.

(2) To be determined/estimated to reflect the cost of Regulatory Compliance.

PREPARATORY PERIOD EXPENDITURES
(amounts in thousands of 1980 dollars)

Date of this analysis 31 Dec 1981

1. Prospecting & Mine Site Evaluation		$ 30,000
2. Research & Development		
2.1 Mining system (including 1/5 scale tests)	60,000	
2.2 Transport system	6,000	
2.3 Process demonstration (1/20 scale test)	70,000	
	SUB-TOTAL	$ 136,000
3. General & Administration		6,000
	TOTAL	$ 172,000

Note: To be written-off over 20 year project life, or, may be considered a sunk cost.

COST BREAKDOWN
(amounts in thousands of 1980 dollars)

Sector	Item	Funding Required	Annual Operating Cost
1.	Continuing Preparations		
1.1	P&E, R&D	$ None	$ 5,000
1.2	Project Management	None	1,000
	TOTAL	$ None	$ 6,000
2.	Mining		
2.1	Mineship (Two, 75,000 DWT, Diesel Elect.)	$ 156,600	
2.2	Handling & Stowage	40,200	
2.3	Pumping System	23,600	
2.4	Dredge Pipeline	45,500	
2.5	Collector Unit	6,000	
2.6	Ore Handling	22,800	
	TOTAL	$ 294,700	$ 68,600
3.	Ore Marine Transportation		
3.1	Ships (Three, 78,000 DWT, Diesel including spares)	$ 173,400	$ 20,300
3.2	Helicopters & Handling Equipment	1,100	600
	TOTAL	$ 174,500	$ 20,900
4.	Ore/Marine Terminal		
4.1	Pier	$ 9,100	$ 200
4.2	Ore Discharge & Storage	18,700	21,000
4.3	Site Improvement & Rent	900	300
4.4	Buildings	1,300	100
	TOTAL	$ 30,000	$ 2,700

COST BREAKDOWN
(Continued)

Sector	Item	Funding Required	Annual Operating Cost
5.	Onshore Transportation		
5.1	Port-to-Plant Slurry System	$ 15,200	$ 4,800
5.2	Plant-to-Waste Site Slurry(1) System	19,900	2,500
5.3	Rail Lines	3,100	200
5.4	Access Road, Exterior(2)	1,500	None
	TOTAL	$ 39,700	$ 7,500
6.	Processing		
6.1	Materials Storage, Handling and Preparation	$ 72,900	$
6.2	Nodule Reduction and Leaching	54,800	
6.3	Metals Separation	45,000	
6.4	Metals Recovery and Purification	95,400	
6.5	Reagent Recovery and Purification	51,700	
6.6	Plant Services	137,400	
6.7	Land	1,000	
	TOTAL	$ 458,200	$ 100,100
7.	Onshore Waste Disposal		
7.1	Land (2500 acres)(3)	1,000	
7.2	Decant Pond	2,500	
7.3	Slurry Distribution System	600	
7.4	Waste Ponds	18,700	
	TOTAL	$ 22,800	$ 6,900(4)

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(1) No salvage value.

(2) Donated to local government - written off in year 1.

(3) Donated to State or County at end of project.

(4) Reduced by $650 K/year in years 1 and 2 as original plant includes 3 ponds.

COST BREAKDOWN
(Continued)

Sector	Item	Funding Required	Annual Operating Cost
8.	Additional Support/G&A		
8.1	Hi-Speed Crew/Supply Boat	$ 1,300	$ 1,300
8.2	Supply Terminal	None	400
8.3	Research Vessel	None	3,200
8.4	Crew Training	None	700
8.5	Headquarters(1)	None	4,000
8.6	Commissions/Fees(2)	None	6,300
	TOTAL	$ 1,300	$ 15,900
9.	Regulatory(3)		
9.1	Environmental	$	$
9.2	Conservation		
9.3	Procedural		
	TOTAL	$ None	$ None
	GRAND TOTAL (All Sectors Except Sector 9)	$1,021,200	$ 228,600(4)

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(1) Headquarters space and equipment are rented.

(2) Use 1.5% of total revenues as sales commission or "take-down" discount.

(3) Capital and Annual Operating Costs to be assumed/estimated to evaluate impacts of Regulatory Compliance on profitability.

(4) Local taxes, royalties and insurance costs are included in each sector Annual Operating Costs.

CAPITAL REQUIREMENTS - BUILD UP
(amounts in thousands of 1980 dollars)

	YEAR						
FUNDING REQUIREMENTS	1[1]	2	3	4	5	6	Total
Capital Items							
Sector 2. Mining	$ 6,700	$10,000	$ 38,000	$ 60,000	$100,000	$ 80,000	$ 294,700
3. Ore Transportation	--	--	--	35,000	89,500	50,000	174,000
4. Marine Terminal	--	5,400	8,200	8,200	8,200	--	30,000
5. Onshore Transport	4,700	--	5,800	13,500	11,700	4,000	39,700
6. Processing	--	40,000	110,000	130,000	120,000	58,220	458,200
7. Onshore Waste Disposal	--	--	--	1,000	14,000	7,800	22,800
8. Support/Services	--	--	--	--	--	1,300	1,300
SUB-TOTAL	$11,400	$55,400	$162,000	$247,700	$343,400	$201,300	$1,021,200
Costs To Be Written Off							
Sector 1. Continuing Prep	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 36,000
8. General & Administrative[2]	4,000	4,000	4,000	4,000	4,000	4,000	24,000
- Plant Testing[3]	--	--	--	--	--	50,000	50,000
- Mine Ship & Transport Testing[4]	--	--	--	--	--	16,200	16,200
SUB-TOTAL	$10,000	$10,000	$ 10,000	$ 10,000	$ 10,000	$ 76,200	$ 126,200
GRAND TOTAL[5]	$21,400	$65,400	$172,000	$257,700	$353,400	$277,500	$1,147,400

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[1] Year 1 is 1986 in this analysis.
[2] Headquarters and permits only.
[3] Includes 50% of Sector 6 Annual Operating Cost.
[4] Includes 50% of Sector 3, 4, & 5 Annual Operating Cost.
[5] Demonstration plant continued operation costs offset by metal revenues.

ANNUAL SALES AND REVENUE BREAKDOWN

Date of this analysis 31 Dec 1981

Product	Ore Assay[1] (%)	Process[2] Efficiency	Yield (tons)	Unit Price[3] ($/#)	Sales ($ x 1000)
Nickel	1.30	.94	36,660	3.75	$274,950
Copper	1.10	.94	31,020	1.25	77,550
Cobalt	0.25	.70	5,250	5.50	57,750
			SUB-TOTAL		$410,300
Secondary (3% of Ni, Cu and Co value)					12,300
		TOTAL PRODUCT SALES (ANNUAL REVENUE)			$422,600

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(1) May be varied to evaluate alternate ore assays.

(2) May be varied to evaluate alternate process efficiencies (metal recovery).

(3) May be varied to evaluate alternate market price forecasts.