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The Economic Viability of a Four-Metal Pioneer Deep Ocean Mining Venture

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OF A FOUR-METAL PIONEER DEEP OCEAN MINING VENTURE

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ABSTRACT

A pioneer deep ocean mining venture is described. This vertically integrated venture explores, transports and processes manganese nodules into four metals and markets the products.

The integrated system is defined, and capital and operating costs are estimated in 1982 U.S. dollars. A basic return-on-investment or payout analysis model is presented and used to evaluate the financial returns of the project. Several alternative cases are investigated. A series of tests is performed to determine the venture's sensitivity to realistic variations of key costs and schedule.

For a gross investment of $1.43 billion, including a fixed plant costing $870 million, a system can be constructed having a 1.5 million dry short ton annual throughput. With output of manganese, nickel, copper and cobalt, net sales of $525 million annually can be obtained. The simple annual average profits are $193 million before taxes and $136 million after taxes, with standard federal tax treatment using the 1982 five-year plant depreciation, ten percent investment tax credit and 15-year carryforwards. Using the discounted cash flow analysis, the before-tax internal rate of return is 8.8 percent. It is 6.4 percent after taxes.

Considering the degree of risk involved, this four-metal, low-throughput mining system is not an attractive investment candidate under the base case conditions.

The four-metal smelting base-case venture is more attractive than the previously evaluated [ref. 17] three-metal reduction/leach plant however, because the manganese revenues are obtained at relatively low incremental capital and operating costs. The ammoniacal leach, three-metal plant analyzed previously is updated in cost to 1982 levels, and the payout program used with the same unit sales prices as in 1980. This larger plant (of three million short dry tons of annual nodule throughput) is less attractive after two years of inflation, yielding only 4 percent discounted after tax internal rate of return (IROR). The addition of a tailings processing plant for manganese to the three-metal plant, increases the revenues substantially by $675 million, at expected levels of investment and operating cost. Thus, the profit from manganese production increases from $144 million before and $125 million after taxes, to $491 and $327 million, respectively. Thus, yields of 16.4 percent before and 12.4 percent after tax internal rate of return are achieved.

The Pacific Northwest alternate location for the base-case, four-metal plants was also evaluated. Because of the very low power cost, this location shows a 9.8 percent after-tax internal rate of return.

This Pacific Northwest location can also benefit the three-metal plant with tailings processing added, because chartering of foreign ships, accelerated construction, in-port location of the process plant, and tax advantages are possible. With extensive governmental support, very attractive internal rates of return can be achieved.

The key to substantial improvements in returns is to develop new processing techniques, especially those that reduce energy requirements, appropriate to the unique characteristics inherent in manganese nodules.

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Dr. J. Dan Nyhart of the Massachusetts Institute of Technology developed the original "Cost Model of Deep Ocean Mining and Associated Regulatory Issues," which led to this team's effort to develop a simplified payout analysis technique at Texas A&M University.

The description and cost estimates in the Processing and Waste Disposal sectors are the consulting contributions of Dr. Francis C. Brown, assistant professor of Chemical Engineering at Northeastern University in Boston, Mass. and also a key member of the original Dames and Moore research team on nodule-processing and metal-winning. Mr. Gerard McCoy, a graduate student in Ocean Engineering at Texas A&M, prepared and exercised the computer programs for this analysis and wrote the computer programs. Miss Lynn Pokryfki, an oceanographer and graduate student in Ocean Engineering at Texas A&M, prepared much of the monitoring and surveying analysis in Chapter IV and was assisted substantially by Mr. McCoy in the instrumentation selection.

We sincerely appreciate the efficient work of Mrs. Joyce Hyden, our secretary, for her many contributions in typing, editing and re-typing this report.

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I

INTRODUCTION

The decrease in world industrial production during 1982 has not improved the demand for or increased the prices of the metals found in manganese nodules on the floor of the deep oceans. In fact, some of these metals are selling at prices that were common two decades ago, while inflation has increased other costs four to six times. This illustrates the inelasticity of the metals marketplace and the willingness of the developing nations, the minimum-cost metals producers, to cut prices to obtain hard currency.

On the other hand, the awareness of the Reagan Administration of our nation's vulnerability in the area of strategic metals has led to several studies supporting development of marine metal resources. Publicity given to the rediscovery of the polymetallic sulfides in areas of rapid seafloor spreading and to the Blake Plateau minerals has provided public awareness of the potential of these marine resources. The question remains, how can manganese nodules be profitably mined and processed to yield metals so essential to our national security? This research explores one approach.

Background

In 1982, Flipse [17]* indicated, based on several years' research, that a three-metal deep ocean mining project was not economically

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

attractive. A three-metal project was defined as a project where the primary products are nickel, copper and cobalt. A four-metal project also produces manganese as a major product, while both programs could produce minor amounts of molybdenum, vanadium, zinc and other trace elements, provided that their recovery would enhance the return on investment. The 1982 report [17] recommended that a four-metal program be investigated.

To simplify the payout analysis and to preclude unrealistic returns on investment, the three-metal case analysis was based on all-equity capitalization, i.e. without debt and leverage. And, as carefully explained in the report [17], the program was a "stand-alone" organization, that is, without (a) write-off of expenses by a parent company, or (b) tax benefits such as Investment Tax Credit used by a parent company, or (c) low-cost debt sources. Because the three-metal case was not economical, the four-metal case is examined here using the same stand-alone organization to determine how the private sector might develop deep ocean mining.

During 1978 and 1979, Flipse studied how environmental regulations would affect the potential cost to an ocean mining program. The findings of the Deep Ocean Mining Environmental Study program [30] indicated that monitoring the marine environment for long-term impacts, during continuous commercial operation of the mining ship, was the prime requirement, because the short-term, near-field effects of ocean mining were judged not to be an environmental problem. An additional concern of the report sponsor, NOAA, is to monitor the marine environment at a designated dump site, in the event that processing plant wastes meet the criteria of the Marine Protection Research and Protection Act (Ocean Dumping Law) [13], and this disposal method is used. Progress in characterizing waste products and developing monitoring equipment and techniques suggests that a long-term monitoring and survey system can be defined and its cost estimated, thereby enhancing the value of the payout analysis.

Objectives

The major objectives of the research were to:

1. Define thoroughly a base-case, vertically integrated, four-metal deep ocean mining venture;
2. Estimate the capital and operating costs of the venture in 1982 U.S. dollars; and
3. Analyze the returns, under current tax laws, examining:
   (a) alternate fractions of debt and equity, and
   (b) various debt interest rates.

To perform these analyses, the Texas A&M University payout model was modified. Three other tasks were deemed worthy of investigation:

4. The sensitivity of nodule-processing costs to alternate energy sources;
5. Benefits of manganese recovery from tailings of a three-metal plant; and
6. The definition, including costs, of environmental monitoring for both deep ocean mining sites and at-sea, waste-disposal sites.

The fuel and energy source alternatives, as well as environmental monitoring, would be examined in the four-metal base-case context, but the findings were expected to pertain to the three-metal case as well.

1. The Base Case

The vertically integrated, manganese nodule mining and processing pioneer venture selected as the four-metal case here included prospecting and research programs and a hydraulic mining system designed to mine 2.3 million wet short tons annually. The mining system uses one mining ship, two bulk transport ships to carry the nodules from the mine to the processing plant, an ore-unloading terminal and a smelting process plant remote from the port area. Waste disposal takes place at an arid land site some distance from the processing plant.

The mine-grade nodules of the Clarion-Clipperton fracture zone area assay on a dry basis, 20 to 30 percent manganese, 5 to 10 percent iron, 1.0 to 1.5 percent nickel and 1.0 to 1.5 percent copper, as well as much smaller percentages of molybdenum, vanadium, zinc, titanium and many trace elements. The prospecting and exploration (P&E) program would involve a smaller area, to define a 20-year mine. The research and development (R&D) program would be essentially the same for three- and four-metal programs, except for technical differences in the processing research.

The mining, transport, material handling and waste disposal systems for four metals are all reduced-scale operations of the three-metal program defined in [17]. The four-metal processing and metal-winning plant is markedly different, although the service functions (nodule stockpiling and retrieval, fuel storage and handling, waste handling, roads, rail systems, etc.) are very similar. The entire system is briefly described and costs reported in the following report section.

2. Cost Estimating

Capital and operating costs for the four metal base case venture are estimated by factoring subsector or component element costs for the defined physical facilities and services. Factored capital cost estimates are based upon equipment and physical plant costs obtained from published literature, manufacturers, and proprietary data. The factoring methodology and data used are identical to those used in the previous studies by the authors and assure internal consistency. Cost data are obtained at one of three levels of aggregation: purchased equipments, installed equipment costs, or physical plant costs. Purchased or installed equipment costs are factored to account for costs of material and labor, and summed. Indirect costs for engineering and contingencies are added to arrive at each sector's total fixed plant. Then related investment for plant services is estimated, as well as start up costs.

Measures of size, throughput, and power, are used to develop labor, supplies, fuels, taxes, insurance, maintenance, and like operating cost projections, and in many cases operating costs are escalated from 1980 to 1982 levels using appropriate cost indices.

The cost estimates are in Section II of this report, following the description of each sector.

3. The Payout Analysis

The payout model developed for [17] served its purpose, but required excessive input data, and was somewhat limited in its ability to handle variations of taxation, interest or alternate debt capitalization. The 1981 Economic Recovery Tax Act was modified by the 1982

Tax Equity and Fiscal Responsibility law. Therefore the program was revised extensively, but the purpose, methods, and many of the subroutines were adopted from the computer program for the three-metal case. The Payout Model is discussed in detail in Appendix A and briefly in Section III.

4. Energy Sources

The four-metals smelting process is energy intensive. Different primary energy sources can be used to dry nodules, generate synthesis gas, and produce process steam. Coke and electricity are used in smelting and electrochemical reduction of metals. The base case assumes coal is the primary energy source, with a minimal cogeneration of electricity on the plant site, derived from steam raised to meet the other process requirements. However, coal can be replaced by fuel oil or natural gas, especially if air quality is a problem. If local electrical power costs are too high, all the needed power can be cogenerated at the plant site. Different fuels and power cogeneration schedules require different types and sizes of boilers, fuel handling and plant services. Therefore capital and operating costs of the nodules processing plant of Sector 5 are altered.

These alternatives are described in Section II and evaluated in Section III.

5. Manganese from Tailings

The three-metal process plant discussed in [17] did not produce manganese as a product, but manganese constituted perhaps one-fourth of the plant tailings. Manganese can be recovered from these rejects by a physical separation technique. Therefore, process description, and material and energy balances are developed, and then capital and operating costs estimated. The manganese rejects processing is assumed added in at the design phase to the previously described three million dry short ton yearly plant described in [17]. The complete description of the plant and 1982 cost estimates are also found in Section II of this report.

6. Environmental Monitoring

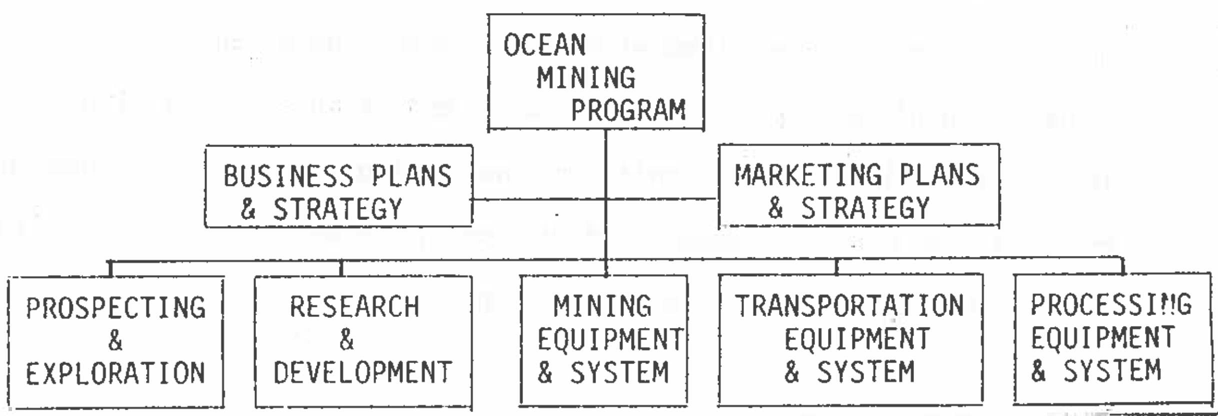
The DOMES report [3] focused on near-term monitoring, not the long-term, far-field effects of ocean mining. This resulted primarily from the short duration of industry tests that were monitored, and the limitations of instrumentation available. Fortunately, the marine instrument industry has developed equipment that can measure and record parameters such as oxygen, nutrients and trace metals, in suspended and bottom sediments. These sediments come from the down-current plume of the bottom collector, overflow from the miner ship, and the deposits at mining and tailings disposal sites. These plumes can cover the benthic organisms and their food supply, and be ingested by fish and larvae near the surface. Monitoring and biological surveys needed to evaluate the long-term impacts of the ocean mining plumes are described as a product of this research in Section IV.

II

FOUR-METAL OCEAN MINING PROGRAM

The hypothetical ocean mining program described below 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



The system described in this report is derived from [17] which is invaluable to the reader in understanding the background, basis, and trade-offs made by the authors in this report. Readers not familiar with ocean mining systems should see [6] and the glossary in [7] for explanations and definitions of terms.

Although many schedule variations are possible, and perhaps likely, the time value of money suggests that once an organization has decided to go into commercial production, (the GO/NO GO decision), every effort will be made to complete construction of the plants, installation of equipment and testing, as soon as possible. Hence, a long preparatory period, followed by a minimum six-year construction period, will result in the schedule for the hypothetical ocean mining program as shown in Figure 2. The 20-year production period was chosen so that equipment replacement schedules and costs would not have to be estimated, thereby greatly simplifying the payout analysis.

Figure 2. Time Schedule

Decision to Go

Year	-15	0	6 — 26
Period	Preparation	Construction	Production
Activity	Research & Development, Prospecting & Exploration, Evaluation	Design, procure, construct, test system	Mine and process nodules; sell products
Time	10-20 years	6 years	20 years

Preparatory Period Expenditures

Most U.S. corporations 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 the Chief Executive Officer. This entity has investigated Deep Ocean Mining to the extent that the C.E.O. will authorize, with Board approval, $3 to $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 and metal winning;
6. Perform simple bench tests (or witness vendor and 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 rate-of-return computer model consistent with <u>their</u> business and financial practices, to determine the potential rewards of deep ocean mining; and
9. Prepare design criteria, specifications and plans, schedules, and budgets for a major research and development (R&D) program to meet commercial objectives.

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

<u>Research and Development</u>

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

Such an R&D program would produce:

1. Component and subsystem tests of the marine mining sector, leading to:
   - ° A one-fifth (approximately) 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 processes, followed by:
   - ° A one-tenth to one-twentieth (approximately) 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 payout 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.
5. Submission of test and environmental monitoring data to NOAA, and receipt of a permit for commercial operations.

Prospecting and Exploration

An early technical problem facing the ocean miner is prospecting for, locating, defining, mapping and evaluating 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 some oceanographic tools have improved, many techniques now used to determine the quantity and quality of a manganese nodule deposit are rather advanced state-of-the-art, while some are truly antique.

A first requirement is a research 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 days or more), 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. Box cores also provide soil and sediment data for scientific correlation and design of mining equipment. The vessel is kept on position by careful use of thrusters and main propulsion, while taut subsurface buoys with acoustic signal generators, and celestial, LORAN, or satellite navigation, help to locate the ship position in the ocean. Normal oceanographic data for scientific or engineering purposes are obtained by standard equipment. The dearth of data on synoptic subsurface, deep-ocean currents or directional waves 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 (at depths of 16,000 ft) to supply accurate micro-topographic 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 placing monitoring arrays, conducting surveys, and prospecting for future mine sites may use all available time. Ten one-month voyages per year would be full vessel usage.

The estimated total cost during the Preparatory Period of the R&D and P&E programs prior to the GO decision is $195 million in 1982. This current value was determined by reviewing previous estimates, by factoring in the reduced scope of the P&E program and the increased uncertainties of the smelting/leaching process R&D program, and by making due allowances for inflation.

The manner in which these costs can be handled in the payout analysis include these three alternative tax treatments for pre-construction expenses described above:

1. SUNK COSTS, where the R&D and P&E expenditures are omitted from the payout calculation. At the time of the GO/NO GO decision, the costs are sunk, as the money is spent whether or not the program is undertaken. In many cases the investors have already expensed these

costs against other income as allowed by the tax code, at least partially recovering them. Therefore, benefits from further tax deductions for these sunk costs are unlikely.

2. WRITTEN OFF NOW, when the monies are spent. This practice would allow the mining company (not the parent) to develop a tax-loss carryforward that must now be used within 15 years of the date the write-off is experienced. This practice is now allowed by the 1982 Tax Equity and Fiscal Responsibility Act (TE & FR) and is used frequently by U.S. companies. This approach would also be necessary for a new partner to buy into a consortium by paying his share of the preparatory expenses. This method of writing off the full $190 million is used in our base case.

3. CAPITALIZED, AND WRITTEN OFF OVER THE LIFE OF THE PROJECT is the most conservative approach and was used in the 1980, three-metal base case [17] because of the old tax interpretations of the IRS prior to the 1982 law. Capitalization of R&D is sometimes differentiated from capitalization of exploration costs. The conventional amortization of preparatory costs over the production period provides the least immediate benefits to cash flow and was not utilized.

These three methods can all be utilized in the TAMU payout model. Cases 2 and 3 show a cash outflow in year one.

Continuing Expenses

During the construction phase, after the GO decision and before commercial operations, the business, marketing and planning management and technical team used to supervise and evaluate the preparatory period activities continues. The management staff consists of well-paid, competent professionals working in rented quarters using rented equipment. Research vessels must continue to define mine sites, and R&D is still needed to improve the new technology. The work described in the preparatory period will be continued during the six-year construction period. The estimated duration of this period 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, research ships and equipment continue to be leased (as in Preparatory Period R&D and P&E), but it does provide $14.1 million per year operating expense for this six-year construction period.

In the sixth year of construction, $93.4 million are provided for the expenses of testing the plant, terminal, vessels and pipelines, and for start-up, initial performance and environmental measurements and analysis. These values represent consensus figures developed from the various consortia, updated in 1982.

Prospecting and Exploration (Sector 1)*

Definition of the expanding mining site and R&D will continue essentially for the life of the program, during the entire commercial production period. During this 20-year period for all the cases, the R&D and P&E operating expenses continue at $6 million annually, and no capital outlay is needed.

*The program was divided in [17] into eight logical cost sectors for capital investment during the construction period, and operating costs during production to assure completeness of cost estimates. These sector notations are again used in this report, with slight differences noted.

[The P&E and R&D of the construction period continuing expenses are split in Sectors 1 and 8 during the commercial operations period.]

Mining (Sector 2)

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

The Mining Ship

The mining equipment of this hypothetical deep ocan mining venture is presented here in sufficient detail to identify the system elements and their capital and operating costs. The mining ship is essentially a single ship from the two miner ship described in [17]. The ship characteristics are:

Length 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. 1982

The ship is draft-limited because of U.S. port limitations, which slightly increases its cost. It can be ballasted to full draft, permitting better ship control and surface reference during the mining or transfer of cargo. The ship hull is strengthened because of the density of the ore and the liquid slurry loads.

The 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. The mining ship is twin-screw, fitted with controllable-pitch propellers and multiple retractable thrusters, both forward and aft. A 40-ft by 50-ft "moon pool" is provided. Superior accommodations are provided for 80 persons, including ship's and mining crews, because of the long duration of deployment. The ship's navigation and communication systems include satellite, Telex, Weather Fax and a long-base-line bottom acoustic system but does not include an automated ship-positioning system. A helicopter landing pad is provided.

The same estimating method for the mine ships, as used in Reference [17], was employed to estimate the capital cost of this ship. Current bulk-carrier costs, both published and unpublished, were modified to provide for the special features required in the mining ship. The result is $91.6 million in 1982.

Handling and Stowage

The costs for handling and stowage of the mining equipment aboard the mining ship are significant and included in this subsector. Equipments include a 25-ton, 60-ft outreach bridge or pedestal crane for launching and retrieving the collector; winches and racks for handling the hose connecting 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 components include a dredge pipe rack, a pipe transfer system, upper and lower derricks, a gimbal platform, a pipe lowering and lift system, and a heave-compensation system. This system is designed to accommodate a three-million-pound load. The estimated cost of this equipment is $23.5 million.

Pumping System

The pumping system selected consists of three multi-stage, motor-driven, mixed-flow pumps located in the upper two-thirds of the dredge pipe string. They pump through the dredge pipe handling system on the gimbal platform. The mining control center provides system data read-outs, stress monitoring, television monitoring, and a control computer provided with manual override.

The estimated cost of the system is $13.8 million, a figure confirmed by parametric analysis.

Dredge Pipe and Bottom Hose

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

A 20-ton (wet) deadweight is employed at the lower end of the pipe string, with special pipe sections providing for the deadweight, pump and motor installation, instrument and controls, dump 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 epoxy 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 sea floor by a buoyant fairing and provides a cable-way for the conductors going to the collector.

Costs were estimated from published and unpublished industry data, comparison with oil-field riser data and confirming parametric analysis. The cost is $17.5 million in 1982.

Collector

The collector must move across the ocean floor at a speed of one to two knots, separating the nodules from the sediments and delivering nodules to the dredge pipe inlet. A typical collector would be approximately 60 ft wide. This collector is a proprietary element of the system, and can slice, pick, wash or otherwise lift the nodules onto ramps, conveyors or ducts to clean them of clinging sediments while delivering them to the dredge pipe. The collector must negotiate small obstacles such as three-foot boulders, while avoiding major obstacles such as cliffs, trenches or wrecks. It can temporarily store excess nodules while it meters into the dredge pipe the correct quantity of nodules to ensure high productivity without overloading the pipe. The collector must function for months without requiring repair or recovery from the bottom. It is outfitted with a seabeam side-searching sonar system to identify obstacles and permit maneuvering of the collector to protect its structure and equipment.

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

Ore Handling

This sub-sector identifies equipment used to transfer the mined ore from the dredge pipe to the ore carriers. The system includes:

1. Hose-and-pipe equipment to accommodate the relative ship/gimbal platform movement, while transferring the nodule and water mixture to a separator where the bottom sediments are returned to the sea and the nodules and recaptured abraded nodule material (fines) deposited on a conveyor;
2. A conveyor that distributes the nodules and fines to the specially configured holds, where they are retained until removed;
3. Reclaimers that deliver the nodules and fines to the stern, where they enter a slurry system that transfers them to the ore transports; and
4. A hose to transfer fuel from the transport to the mining ship.

The estimated cost is $13.3 million.

Capital Costs

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

The total capital costs are shown on Table 1.

Table 1. Capital Cost Estimate for Mining, Sector 2 (Millions of 1982 U.S. Dollars)

		Capital Cost
Mining ship		$ 91.6
Handling and stowage equipment		23.5
Pumping system		13.8
Dredge pipe and bottom hose		17.5
Collector		3.5
Ore handling		13.3
	Subtotal	$163.2
Spare pipe string		17.3
	Total	$180.5

Annual Operating Costs

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

(a) Manning costs, including a 40-man ship crew, a 32-man mining crew, and a full relief crew for the ship, resulting in two 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 costs;

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

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

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

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

300 days mining at 16,000 HP or 65 LT/day
54 days transferring nodules at 9,200 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 6,800 HP or 27 LT/day

Total fuel usage 23,300 LT/year

Annual operating costs are estimated from these values and are given in Table 2.

Table 2. Mining Sector 2 Annual Operating Costs (Millions of 1982 U.S. Dollars)

Manning	$11.2
Maintenance and repair	21.6
Insurance	2.0
Fuel	4.3
Total	$39.1

Ore Marine Transport (Sector 3)

Transport Ships

The small weight of nodules mined annually requires only two ore-transporting ships of about 62,000 DWT. The particulars of the ships and a typical voyage are given in the tables below. A Panamax hull of 108' maximum beam could also be selected. Propulsion is provided by a 17,300 BHP, slow-speed diesel engine. The transport would load nodules in a slurry through a special transfer hose, receiving equipment and distribution piping. Decanting and dewatering systems are provided, but ship discharging is performed at onshore terminal facilities. Data used in price analysis for the transports are reported in [2]. Costs have been increased to account for inflation through 1982, except for fuel costs, which are $27.61 per barrel for residual marine fuel oil and $40 for diesel fuel used by the main engine during maneuvering, and the generators.

Transport Ship Particulars

Number of ships: 2
Length: 720 ft
Beam: 113 ft
Depth: 59 ft
Draft (S.W.): 40 ft
DWT: 62,000 long tons
Speed (loaded): 14.6 knots
Brake horsepower: 17,300 HP
Crew: 28 persons
New construction, U.S.A.

Voyage Particulars

Port to minesite: 1,700 n. miles
Cargo tonnage: 56,000 long tons (90% DWT)
Transit time: 10 days
Loading time: 28 hours
Voyages per ship per year: 24½
Annual usage: 301 days
Annual per ship capacity: 1.51 million short tons
System capacity: 3.02 million short tons

Capital Costs

The data in [17] have been updated to 1982 dollar costs. The data include provisions for handling the transfer hoses for fuel oil and nodules, a ship-board ore distribution system, a helo-pad with fuel service, and a full set of spare parts but do not include Construction Differential Subsidy. The ships' cost in 1982 U.S. dollars is estimated as follows:

Two Ore Marine Transports

Ships and parts	$118.4 million
Helicopter equipment	0.8
Sector 3 Total	$119.2 million

Annual Operating Costs

Annual operating costs are estimated using U.S. crews for the ships but no Operating Differential Subsidy. Helicopters would be provided for transfers to the mining ships. For both ships, operating costs in 1982 dollars are as follows:

Fixed operating cost (including maintenance and repair)	$ 8.55 million
Fuel cost	6.34
Port and lay-up costs	0.30
Helicopter crew and fuel (rental)	0.21
Sector 3 Total	$15.4 million

Ore Marine Terminal (Sector 4)

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

Facility Description

A vacant 15-acre site would be graded, and water, sewer and electrical services would be installed. Access roads within the area would be paved. A dock for the 62,000-DWT ships would be dredged, and a suitable pier or wharf and mooring dolphins would be installed. A major element of the cost is the nodule re-slurrying and unloading system, which includes cranes on tracks to lift the unloading gear into the holds, pumps and hoses, and slurry water storage tanks. Holding ponds would be provided for two shiploads of nodules. Offices and shops for the operating staff, spare parts and stores, and maintenance and repair (M&R) would be built. Fuel pipelines are also provided.

Capital Costs

The berth space (costing almost $2 million for dredging) at a 41'x945' pier, six unloading cranes, building and pipeline costs are:

Ore Marine Terminal

Pier and dock	$ 9.7 million
Ore unloading and storage	18.6
Site improvement	1.0
Building	1.2
Sector 4 Total	$30.5 million

Annual Operating Costs

Annual operating costs were estimated using the same updated formula. M&R and unloading the ships are the major operating costs. The estimated 1982 dollar costs are summarized as follows:

Marine terminal dredging, M&R	$ 0.5 million
Ore unloading and storage	3.0
Site rent, insurance, taxes, utilities	0.3
Building services	0.1
Sector 4 Total	$ 3.9 million

Onshore Transportation (Sector 5)

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

Facility Descriptions

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

A 60-mile-long pipeline delivers the tailings slurry from the plant to the waste site, and includes land and pumping stations. The fine-particle waste slurry is distributed at the waste site by a piping system included in Sector 7.

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

Capital Costs

The sector capital costs in 1982 dollars are:

Onshore Transportation	
Port-to-plant slurry system	$13.7 million
Plant-to-waste site slurry system	7.0
Rail lines	3.4
Access road	2.4
Sector 5 Total	$26.5 million

Annual Operating Costs

About 70 percent of the operating costs for two slurry pipelines is for electric power at 11 cents per kilowatt-hr. Also provided are labor for the pumping stations and pipelines, maintenance and repair (M&R), local taxes, and liability insurance. By sub-sector, the operating costs in 1982 dollars are:

Onshore Transportation

Port-to-plant slurry system	$7.2 million
Plant-to-waste site slurry system	0.8
Rail line	0.3
Sector 5 Total	$8.3 million

Processing (Sector 6)

The technology selected in this analysis for the recovery of nickel, copper, cobalt and manganese from nodules involves smelting them to produce (a) a metallic alloy phase, from which nickel, copper, and cobalt are subsequently recovered using hydrometallurgical techniques, and (b) a slag phase from which manganese is recovered by pyrometallurgical techniques. This general approach has been investigated by some of the consortia active in the development of processing technology. A report by Dames and Moore [7] includes a detailed description of such a process, as well as a four-metal process based on a reductive hydrochloric acid leach, but the manganese product was in the form of electrolytic manganese. The smelting process was selected for this analysis, because the markets for the product forms (ferro- and silico-manganese) are significantly larger than for electrolytic manganese, and fewer questions of market penetration and product pricing need be addressed.

Smelting Process

Copper, nickel, cobalt, and ferro-manganese alloys can be recovered from nodules by a smelting process based on adapting elements of known electric furnace smelting and hydrometallurgical processes.

The nodules are first dried by direct contact with combustion gases and are then reduced, converting manganic and ferric oxides to their manganous and ferrous states, by contact with hot, carbon monoxide-rich producer gas. The hot, reduced nodules are charged to electric furnaces along with coke, fluxes, recycled slag and other reverts. In these furnaces most of the copper, nickel, cobalt, iron and some of the manganese and other impurities are reduced and form an alloy phase that separates by gravity from the manganese-rich slag. This slag, (b) with recycled iron-rich slags, is reduced further with additional coke and fluxes in other electric furnaces to produce ferro-manganese alloys. Slag from these furnaces is reduced again, producing silico-manganese. The waste slag is granulated for disposal.

The alloy phase (a) produced in the first smelting step is transferred to converter vessels where flux is added and the manganese and most of the iron are reoxidized to a slag which is recycled. Coke and gypsum are then added to the alloy, producing a metal sulfide matte phase containing the copper, nickel, cobalt and some iron. This matte is separated from the remaining slag and granulated prior to further processing.

The granulated matte is ground and the metals are extracted by oxidative dissolution in hot sulfuric acid. The metal-bearing solution is subjected to a series of purification and separation steps using liquid ion exchange. Copper and nickel solutions are stripped from the ion exchange reagents, and the metals are recovered as electrowon cathodes. Cobalt is recovered from the free of copper-nickel, leach solution by precipitation with hydrogen sulfide. The sulfide solids are separated from the resulting slurry, and redissolved by leaching.

Cobalt powder is recovered by hydrogen reduction following a series of solution purification steps.

The metal-free leach solution contains ammonium sulfate, and is treated with lime to precipitate soluble sulfates as gypsum . The ammonia is recycled to the metals separation steps for pH control. The gypsum is disposed of, along with residues from the matte leaching step.

Plant services include facilities for generating the producer gas used in nodule reduction, raising necessary steam and part of the power used in the process, supplying make-up and cooling water, and providing for materials handling for process materials and supplies.

The process description presented in the Dames and Moore report [7] was modified somewhat for this analysis. An additional slag reduction step (b) was added to permit the production of silico-manganese, as well as ferro-manganese, thereby increasing overall manganese recovery from the nodules by 15 percent. In addition, an electrode preparation plant was included in the scope of the process plant and the material and energy balances were revised to accommodate a throughput of 1.5 million short tons of dry nodules. The elements of the processing plant are identified in the detailed capital cost breakdown of Table 3, grouped in sub-sectors for the major operational divisions of the plant.

The four-metals base case plant configuration for which the costs below were derived, uses coal as the primary energy source, with minimal cogeneration of electric power on-site. The plant location is assumed to be in Southern California, and allowances have been made for the costs of controlling emissions from the smelting and coal combustion

Table 3. Capital Cost Breakdown Four Metals/Smelting Process Plant

		Purchased Equipment Cost $\$ \times 10^3$	Factor for Equipment Installation @40%, $\$ \times 10^3$	Installed Equipment Cost $\$ \times 10^3$	Total Installed Equipment $\$ \times 10^3$	Factor for Physical Plant @90%, $\$ \times 10^3$	Physical Plant Cost $\$ \times 10^3$	Total Physical Plant $\$ \times 10^3$	Factor for Indirects @50%, $\$ \times 10^3$	Total Plant Cost $\$ \times 10^3$
Subsection 3.1:	Materials Storage, Handling, and Preparation									
3.1.1	Rail Car Station	290		630						
3.1.2	Coal and Coke Stacking, Storage, and Reclamation	3,000					3,460			
3.1.3	Limestone Stacking, Storage, and Reclamation	650					350			
3.1.4	Nodules Receiving and Storage			5,380						
3.1.5	Nodules Reclamation and Transfer	1,710								
3.1.6	Nodules Grinding and Drying and Offgas Treatment	6,990		660						
3.1.7	Lime Storage and Slaking	650					350			
3.1.8	Electrode Materials Storage and Reclamation	510					120			
3.1.9	Silica Stacking, Storage, and Reclamation	650					230			
3.1.10	Gypsum Storage and Reclamation	650					450			
		15,100	6,040	6,670	27,810	25,030	4,960	57,800	28,900	86,700
Subsection 3.2:	Nodules Reduction and Metals Extraction									
3.2.1	Dried Nodules Feeding and Reduction	2,500		810						
3.2.2	Offgas Treatment: Reduce, Smelt, Convert	1,400		1,790						
3.2.3	Reduced Nodules Smelting	950		660			15,100			
3.2.4	Electrode Paste Preparation	1,110		280						
3.2.5	Converting	600		250			2,790			
3.2.6	Ferromanganese Reduction	600		800			15,100			
3.2.7	Silicomanganese Reduction	440		450			10,600			
3.2.8	Offgas Treatment: Fe Mn, Si Mn Reduction	1,450		1,820						
3.2.9	Hot Metal Transfers and Services						20,400			

Table 3. Continued

	Purchased Equipment Cost $\$x10^3$	Factor for Equipment Installation @40%,$\$x10^3$	Installed Equipment Cost $\$x10^3$	Total Installed Equipment $\$x10^3$	Factor for Physical Plant @90%,$\$x10^3$	Physical Plant Cost $\$x10^3$	Total Physical Plant $\$x10^3$	Factor for Indirects @50%,$\$x10^3$	Total Plant Cost $\$x10^3$
Subsection 3.2: Continued									
3.2.10 Smelter Fugitives Control	2,700		1,730						
3.2.11 Granulation and Casting	1,100		730			6,600			
3.2.12 Matte Leaching	140		1,740						
3.2.13 Liquor pH Adjustment	290		500						
3.2.14 Dusts Conditioning	2,470		780						
	15,750	6,300	12,340	34,390	30,950	70,590	135,930	67,970	203,900
Subsection 3.3: Metals Separation									
3.3.1 Copper Extraction and Stripping }						}			
3.3.2 Nickel Extraction and Stripping }						}			
3.3.3 Ammonia Scrubbing }						}			
3.3.4 Cobalt Stripping and Solvent Recovery }						31,170			
3.3.5 Raffinate Neutralization			610						
			610	610	550	31,170	32,330	16,170	48,500
Subsection 3.4: Reagent Recovery and Purification									
3.4.1 Ammonia Recovery and Lime Boil			950						
3.4.2 Process Vent Scrubbing			120						
3.4.3 Gypsum Slurry Separation			250						
3.4.4 Waste Slurry Storage, Treatment and Transfer			430			1,050			
3.4.5 Slag Storage & Transfer	80		220						
	80	30	1,970	2,080	1,870	1,050	5,000	2,500	7,500

Table 3. Continued

	Purchased Equipment Cost $\$x10^3$	Factor for Equipment Installation @40%, $\$x10^3$	Installed Equipment Cost $\$x10^3$	Total Installed Equipment $\$x10^3$	Factor for Physical Plant @90%, $\$x10^3$	Physical Plant Cost $\$x10^3$	Total Physical Plant $\$x10^3$	Factor for Indirects @50%, $\$x10^3$	Total Plant Cost $\$x10^3$
Subsection 3.5: Metals Recovery and Purification									
3.5.1 Copper Electrowinning						13,700			
3.5.2 Nickel Electrowinning } 3.5.3 Organic Removal						20,300			
3.5.4 Mixed Sulfides Precipitation and Separation	660		130						
3.5.5 Selective Leaching and Solution Purification	390		20						
3.5.6 Nickel Reduction and Sintering	350		10						
3.5.7 Cobalt Reduction and Sintering	990								
	2,390	960	160	3,510	3,160	34,000	40,670	20,330	61,000
Subsection 3.6: Plant Services									
3.6.1 Water Supply and Purification System			2,940						
3.6.2 Cooling Water System						3,230			
3.6.3 Process Steam System						13,700			
3.6.4 Process Gas System						21,900			
3.6.5 Offgas Treatment/Services			4,570						
3.6.6 Plant Power Generation			4,380						
3.6.7 Process Materials, Supplies, Fuel, and Product Storage	1,380		300						
3.6.8 Service Buildings } Included in									
3.6.9 Site Services } PCC Factor									
	1,380	550	12,190	14,120	12,710	38,830	65,660	32,840	98,500

Total Fixed Capital Investment, Excluding Land $\$506,100 \times 10^3$

operations. (Alternate plant configurations are described in following sections.)

Capital Costs

Fixed capital requirements for the processing sector were developed by a factored estimating technique. The process plant was divided into functional sub-sectors and further divisions, to take advantage of the organization of data in the cost-estimating literature.

The revised material and energy balances for the plant were used, with equipment design criteria relating to throughput, to estimate the sizes and costs of individual equipment items or of assemblies of equipment items such as the electrowinning plants. Estimates were obtained on the basis of purchased, installed or physical plant cost data. The costs of materials and labor for equipment installation, commodities (e.g., piping and instrumentation) and indirect costs for engineering and construction were estimated as percentages, or factors, of equipment costs. The costs of plant services and support operations were estimated by the same general procedure.

The processing sector capital costs are presented below. Summarizing by sub-sector, for the base case, producing four metals from 1.5 million dry short tons of nodules per annum, the costs are:

Materials storage, handling and preparation	$ 86.7 million
Nodules reduction and metals extraction	203.9
Metals separation	48.5
Reagent recovery and purification	7.5
Metals recovery and purification	61.0
Plant services	98.5
Sector 6 Total	$506.1 million

Annual Operating Costs

Annual direct operating costs were estimated from the material and energy balances, the estimated capital costs, and a manning table. Annual costs in each category are the product of annual consumptions for 330 days of operation and unit costs, in 1982 dollars.

Consumption of raw materials, supplies and fuels was taken from the material and energy balances. Power consumption for process drives was estimated at the sub-subsector level, and power requirements for electrowinning and manganese reduction were obtained from the literature. Total plant labor costs were obtained by adding allowances for fringe benefits and general and administrative costs to the direct labor costs in all categories in the plant. Fixed costs for maintenance materials and supplies, insurance and taxes were estimated as a percentage of the plant fixed capital requirement.

A detailed breakdown of the annual operating costs for the processing plant is presented in Table 4 and summarized by sub-sector for the base case in 1982 dollars:

Sector 6 Items

Materials and supplies	$ 18.8 million
Fuel and water	52.0
Purchased power	119.1
Labor	22.9
Fixed costs	40.5
Sector 6 Total	$253.3 million

Waste Disposal (Sector 7)

The amount and nature of the wastes from a four-metal smelting plant differ from those produced in a three-metal hydrometallurgical plant. Most of the rejects are in the form of a vitreous slag, which is coarse, free-draining, and of high density. While this material might well find use as a construction material and thereby provide

Table 4. Operating Cost Breakdown Four Metals/Smelting Process Plant

Component	Annual Consumption	Unit Cost	Annual Cost $\$x10^3$/Year
Materials & Supplies			
Limestone	33.6M tons/year	\$23/ton	773
Silica Flux	69M tons/year	\$23/ton	1,587
Lime	62M tons/year	\$37/ton	2,294
Gypsum	111M tons/year	\$33/ton	3,663
Electrode Materials	7M tons/year	\$110/ton	770
Oxygen	59M tons/year	\$78/ton	4,602
Ammonia	1,250 tons/year	\$160/ton	200
Hydrogen Sulfide	2,600 tons/year	\$220/ton	572
Hydrogen	72MM ft^3/year	\$3.7/M ft^3	266
Nitrogen	190MM ft^3/year	\$1.1/M ft^3	209
Chlorine	100 tons/year	\$145/ton	15
Sulfuric Acid	41M tons/year	\$80/ton	3,280
Ion Exchange Reagents	7M gal/year	\$27/gal	189
Kerosene	28M gal/year	\$1.1/gal	31
Flocculants	8 tons/year	\$2.2/lb	35
Filter Aid	630 tons/year	\$110/ton	69
Electrowinning Additives	8 tons/year	\$600/ton	5
Sodium Sulfate	700 tons/year	\$90/ton	63
Boric Acid	100 tons/year	\$552/ton	55
Activated Carbon	20 tons/year	\$600/ton	12
Sodium Chloride	50 tons/year	\$50/ton	3
Water Treatment Chemicals	250 tons/year	\$550/ton	138
	TOTAL MATERIALS & SUPPLIES		18,831

Table 4. Continued

Component	Annual Consumption	Unit Cost	Annual Cost $\$x10^3$/Year
Utilities & Fuel			
Coal	400M tons/year	$50/ton	20,000
Coke	259M tons/year	$110/ton	28,490
Fuel Oil	2.5MM gal/year	$1.1/gal	2,750
Water	1198MM gal/year	$0.6/M gal	719
Purchased Power	1083MM kWhr/year	11¢/kWhr	119,130
	TOTAL UTILITIES & FUEL		171,089
Labor			
Management & Professional	60 MY	$46x10^3$\$/MY	2,760
Clerical & Administrative	50 MY	$23x10^3$\$/MY	1,150
Operating & Maintenance Supervision	60 MY	$34x10^3$\$/MY	2,040
Senior Operators/Maintenance	60 MY	$29x10^3$\$/MY	1,740
Operators & Maintenance	310 MY	$23x10^3$\$/MY	7,130
Plant & Operations Support	60 MY	$18x10^3$\$/MY	1,080
	Total Direct Salaries		15,900
Direct Fringes @25% of Salaries			3,975
	Total Compensation Cost		19,875
Plant & Corporate G&A and Overhead @15%			2,985
	TOTAL LABOR COSTS		22,860

Table 4. Continued

Component	Annual Consumption	Unit Cost	Annual Cost $\$ \times 10^3$/Year
Fixed Charges (on $\$506.1 \times 10^3$ TFC)			
Maintenance Materials		5% TFC	25,305
Operating Supplies		1% TFC	5,061
Patents/Royalties/Fees		--	--
State/Local Taxes		1% TFC	5,061
Insurance		1% TFC	5,061
	TOTAL FIXED CHARGES	@8% TFC	40,488
TOTAL DIRECT OPERATING COSTS			253,268

additional revenue to the venture, this analysis assumes that slag will be disposed of in a controlled slag dump located adjacent to the plant site. Smaller amounts of manufacturing wastes, such as lime boil and scrubber sludges, will be disposed into slurry settling ponds located far from the plant. For a 20-year project life, 100 acres are required for slag disposal, and a 500-acre site would be required for at least 20 five-acre slag ponds and 75-acre decant pond.

Capital Costs

The capital costs of the waste disposal system include construction of containment areas for the first three years of operation, as well as the decant pond, slurry distribution system and necessary monitoring systems. Costs of slag handling equipment are included in the processing sector.

The costs of the disposal areas were estimated by adding the costs of site preparation, dike construction, drainage trenches and seepage monitoring and control equipment, and installation of an impervious liner in the ponds. These costs are in 1982 U.S. dollars:

Land	\$0.3 million
Decant pond	2.4
Slurry distribution system	0.5
Disposal areas and initial pond construction	2.4
Sector 7 Total	\$5.6 million

Annual Operating Costs

Annual operating costs of waste disposal include labor and materials to prepare new areas and build new ponds beginning at Year 2; reclamation of the areas previously used; and materials, labor and maintenance to support operations in the disposal area. These costs are in 1982 dollars:

Materials, supplies and labor	$0.25 million/year
New area construction	0.85
Sector 7 Total	$1.1 million/year

Additional Support and General and Administrative (Sector 8)

Certain costs do not fit the seven sectors described previously, and are included here. Most of this equipment can be chartered or rented. An exception is the crew and supply boat because of its high capacity and speed, the distance to the mining site, and the large number of passengers carried. The terminal for this boat is assumed to be rented from the Port Authority of a metropolitan city (e.g., San Diego, Hilo, or Honolulu) that will also serve as the base of operations of the chartered research vessel. Crew members of the mining ship and transport personnel will be trained by others (the Kings Point research facility or commercial services) to assure the required ship handling competence.

A headquarters staff, housed in rented offices, provides the usual management, financial, legal and marketing services necessary for or incidental to smooth operation of the project. This staff is different from the management personnel at the processing plant, the ore terminal and the supply base. Space, facilities, support staff and salaries are provided in Sector 1 for R&D and P&E personnel during the commercial production period.

Capital Costs

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

Annual Operating Costs

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 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 ten one-month voyages per year. Both mining ship and transport crews will be trained by others (to a rigid specification). This cost sub-sector provides for that training, as well as travel, subsistence and replacement personnel that will man the ships during training of the regular crews.

A high-quality rented office complex (perhaps in the port or the processing plant area) with rented equipment is included in this sector. A management organization is assumed, 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. Annual operating costs, in 1982 dollars, are:

High-speed crew supply boat	$0.9 million
Supply terminal	0.4
Research vessel	3.5
Crew training	0.2
Headquarters	4.0
Sector 8 Total	$9.0 million

The Sector 1 P&E and R&D staff costs of $6 million annually, plus these Sector 8 costs of $9 million, total $15 million, compared to the construction period amount of $14.1 under Continuing Expenses.

Regulatory

The National Oceanic and Atmospheric Administration (NOAA) funded the research reported in [17] with the main objective of developing a cost model of an ocean mining project that could determine realistically the effects on profitability of alternate regulatory regimes. The Texas A&M University Payout Model permits such an evaluation for the base case covered in this report. The principal task was to determine a realistic environmental monitoring system to determine the long-term, far-field effects, if any, of operating a deep ocean mining ship in the Clarion-Clipperton fracture zone.

The costs of regulation can be broken down into the following categories [17]: environmental, conservation and procedural. If we assume that the principal regulatory cost is environmental, we can use the cost estimates developed in the monitoring section (Section IV) of this report. These costs are then added, in both the capital and operating cost categories, to the Sector 8, Additional Support and General and Administrative.

The regulations to be promulgated under the law currently are undergoing public scrutiny in the review process. Flipse's analysis, "The Potential Cost of Deep Ocean Mining Environmental Regulation" [16], suggested certain regulations and estimated their costs. Each investigator is expected to use his judgment in estimating capital costs in this sector. In the base-case analysis, these costs were taken as zero.

Each investigator also is expected to use his judgment in estimating annual operating costs. Flipse [16] found that at-sea environmental protection costs should be insignificant and should not influence returns estimated by this Payout 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, in the categories of cash, accounts receivable and payable, and inventories. Parameters included initial supplies of fuels and reagents, stockpiled manganese nodules, material in process, stockpiled finished products, products in transit, accounts receivable and collection costs, nodule and federal income taxes, and operating costs. The resulting estimates varied widely.

The working capital computation includes three months' nodule inventory at cost, three months' finished products in stock for delivery commitments, and three months' raw materials and fuels in stock to avoid plant shut-downs, plus three months' average tax payment. These four categories total almost $131 million for the base case. In addition, one month's nodule tax, one month's total system operating cost, and one month's carrying of accounts receivable (including delivery time) are estimated. During the process cycle, five days' work in progress is also funded. Offsetting accounts payable are limited to wages, only 10 percent of operating costs for two weeks, and trade accounts for the remaining 90 percent with four weeks' terms. The total working capital was rounded to $190 million, which corresponds to the previous estimates after escalation to 1982 dollar value.

This working capital computation result is a higher fraction of sales than normal for a metals and mining company. However, considering the complicating factors of a higher proportion of fuels and reagents in the system, the higher costs of the high-grade stockpiled nodules, which are not mined next to the plant, working capital of 190 million 1982 U.S. dollars is realistic, perhaps even conservative. The extended at-sea system test before commercial production begins is priced as a continuing expense in Year 6.

Base Case Cost Summary

Total capital and operating costs for the four-metal plant processing 1.5 million dry short tons per year are given in Table 5. Also shown are the preparatory period expenses prior to GO, the continuing expenses during construction, and the working capital, which is considered invested in Year 6, just before commercial production commences. The summary figures are rounded to no more than three significant figures, and to no less than the nearest $100,000.

Revenues

Revenue is determined by several key factors, including ore assay, annual throughput, efficiency of the metal-winning process and 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 1.5 million short tons of dry nodules for the four-metal plant. An equally important decision is the nodule

Table 5. Summary of Sectors and Costs for Four-Metal Base Case (millions of 1982 U.S. dollars)

Sector	Item	Fixed Plant Capital Cost	Annual Operating Costs
1	R&D, P&E	0	6.0
2	Mining	$180.0	39.1
3	Ore Marine Transportation	119.0	15.4
4	Ore Marine Terminal	30.5	3.9
5	Onshore Transportation	26.6	8.3
6	Processing	506.0	253.0
7	Onshore Waste Disposal	5.6	1.1
8	Support/G&A	1.6	9.0
	TOTALS	$869.3	$335.8
	Preparatory Period Expenditures	195.0	
	Continuing Expenses	178.0	
	Working Capital	190.0	
	Total Funding Invested	$1,423.3	

assay to determine the metal content of the four metals. In this project we used nickel at 1.30 percent, copper at 1.10 percent, manganese at 29.0 percent, and cobalt at 0.25 percent, on a dry-weight basis. This assay agrees with the literature for mine-grade nodules. The efficiency of metal recovery by various processes has been studied in depth. Recovery rates of 95 percent for nickel and copper, 93 percent for manganese and 85 percent for cobalt are realistic for the four-metal process selected as the base case. Careful metallurgical controls of all process operations are needed to assure these high recoveries. Secondary metal recovery in this hydrometallurgical process is limited to about one percent of the value of the metals obtained in the process. The revenues are summarized in Table 6.

Table 6. Base Four-Metal Case Revenues

Annual Yield = 1,500,000 short dry tons

Product	Efficiency (%)	Assay (%)	Yield (short tons)	Price ($/lb)	Sales (millions of US 82 $)
Manganese	93	29	404,550	0.40	323.6
Nickel	95	1.30	18,525	3.75	138.9
Cobalt	85	.25	3,375	5.50	35.1
Copper	95	1.10	15,675	1.25	39.2
TOTAL					536.8
Secondary products (1% of Ni, Co, Cu, Mn)					5.4
TOTAL REVENUE					542.2
Less commissions, escrow, and freight (3.25%)					17.6
Net Revenues					524.6

Cost Variations

The reliability of the cost estimates varies for different system sectors. Some costs of standard systems and installations are estimated quite easily and with relatively good accuracy. For example, ±15 percent would cover the range of expected costs of buildings, piers or vessels. At the other extreme, costs of incompletely defined equipment for a process plant of a type that has never been built before, may range from 20 percent less than the estimate to 40 percent more and likely will differ from the best estimate by 25 percent.

The proper procedure to estimate the possible spread of costs for each item would be to perform a statistical analysis of the variability of the cost data used in selecting our central value cost estimates.

We had the problem of deciding on the level of disintegration at which to estimate the cost variations from the central values used thus far in the TAMU cost model.

We had eight sectors, 38 subsectors, and approximately 150 sub-subsectors. To analyze the 150 sub-subsectors would require data, computer time and cost beyond that which could be accomplished on this project. Also, many of these detailed cost items are not based on historical data, eliminating the detailed analysis possibility. If the subsector mix of costs is used, some sub-subsectors are more variable than others, and some costs probably are interdependent in the aggregation to subsector level. Thus, the more rigid statistical approach applied to subsectors is not feasible, and at this level, educated guesses may be as valid as analytical approaches.

Review of the basic texts on random cost variations indicates that rigorous statistical solutions are applied to extensive factual data and not provided for forecasting purposes.

The 1980 base costs of the elements of the transportation sectors were examined in detail because sufficient data were available. Table 7 shows, for all transportation subsectors, the low and high limits, expressed as percentage change from the 1980 base cost, of the distributions of capital and operating costs, as well as the type of distribution. Extensive data were available for transport ship capital and operating costs, pier and ore discharge capital costs, site improvements and buildings, tailings pipelines, railways and highways. This gives good confidence in the ranges of their cost distribution and the type of cost distribution.

The cost ranges are much higher than expected, even on the more standard construction jobs, such as piers, which was one of a few items analyzed statistically by computer. The range limits were put at ±3 standard deviations, or about 99.7 percent of all the data. Other sub-sector costs were factored in on a cost-weighted basis, with range estimates taken from whatever data were available.

The relatively large cost ranges were caused by the following factors, in order of importance: slurry power requirements, labor intensity, building site conditions, new designs and competitive conditions. The slurry power requirements depend upon particle size and mix, flow velocity, pipe size, changes in elevation, and routing. For the nodules in particular, where fine particle size is not assured, the power requirement and unit costs may increase vastly over the

Table 7. Cost Distributions of Transportation Subsectors
(3 million dry short tons, p.a., 1980 costs, three-metal case)

		Base Cost ($ thousands)	(C/O) *	Low Limit (-%)	High Limit (+%)	Distribution Type
3.1	Three 78,000 DWT transports + spares	173,400 20,300	C O	-15 -12	+15 +25	Normal Skewed
3.2	Helicopters & Handling Equipment	1,100,000 600,000	C O	-20 -20	+40 +20	Skewed Normal
		(dollars)				
4.1	Pier-Ore terminal	9,100,000 200,000	C O	-30 -15	+50 +30	Skewed Ramp
4.2	Ore discharge & storage	18,700,000 2,100,000	C O	-25 -50	+40 +300	Ramp Ramp
4.3	Site improvements & rent	900,000 300,000	C O	-20 -10	+30 +20	Skewed Ramp
4.4	Buildings	1,300,000 100,000	C O	-40 -20	+50 +20	Skewed Normal
5.1	Port-plant nodule pipeline	15,200,000 4,800,000	C O	-50 -75	+100 +900	Skewed Skewed
5.2	Plant to waste tailings pipeline	19,900,000 2,500,000	C O	-20 -15	+40 +75	Skewed Skewed
5.3	Rail lines	3,100,000 200,000	C O	-50 -20	+50 +20	Ramp Normal
5.4	Exterior access roads	1,500,000 0	C O	-20 ---	+50 ---	Ramp ----
8.1	Hi-speed crew-supply boat	1,300,000 1,300,000	C O	-20 -50	+50 +50	Ramp Ramp
8.2	Supply terminal rental	0 400,000	C O	--- -15	--- +15	---- Normal
8.3	Research vessel, chartered	0 3,200,000	C O	--- -30	--- +30	---- Ramp
8.4	Crew training	0 700,000	C O	--- -50	--- +50	---- Ramp

*C = Capital Cost
O = Operating Cost

base-case assumptions. Tailings are expected to be fine, so less power variation is expected for the tailings pipeline. Several operating labor unions are able to demand relatively high wages and manning for waterfront and maritime activities. Among those having strong possible cost impacts are the longshoremen, pier construction and vessel crews.

Building conditions have been assumed as average without specific description. However, poor soils with inadequate strength, excessive rock, and rough terrain, for the road and railways especially, could boost costs substantially.

New designs could significantly escalate costs of the high-speed, long-range crew-supply boat, and of several design aspects of the slurry pipelines, such as hopper loading, for abrasion reduction and additives.

Competitive conditions, when relatively few suppliers can produce the product or service, may increase costs for certain unusual items. These poor-competition areas include special-design slurry facilities, the crew-training simulator and the on-board helicopter service.

These data-derived values may be summarized for each of the transport sectors totals as follows:

Sector	99.7% Estimate low	high
3. Nodule Transport	C-16	+17
	0-13	+24
4. Nodule Terminal	C-27	+42
	0-45	+250
5. Land Transport	C-35	+60
	0-53	+600
8. Maritime Support	C-20	+50
	0-35	+40

The greatest cost range tends to exceed the base cost by a greater amount than the base cost exceeds the smaller cost range. Also, the capital cost is dispersed less than the operating cost estimates, for the reasons given before. These numbers were added first for the negative ranges, then for the positive ones. For all transport sectors combined, 1980 capital cost estimates could range from about -20 to +27 percent, and operating costs from -29 to +225 percent. However, the probability of all items reaching these extreme values simultaneously is very small, and it is essentially zero that all the extremes will occur together. Monte Carlo simulation, by random number selection, as the probability of occurrence of a specific cost would be the proper procedure to follow, but insufficient data are available to pursue this approach in other, larger cost-and-risk sectors, except, perhaps, for conventional waste disposal.

Therefore, for sensitivity analyses, cost ranges of ±30 percent were generally used for computation of the extreme ranges of payout periods and internal rate of return, before and after taxes. However for certain sector components, discussed next, other cost ranges were selected as more appropriate.

Alternative Energy Mixes

The four-metal smelting process is quite energy-intensive and requires energy input in a variety of forms. Fossil fuels provide energy for drying the wet nodules and for generating the synthesis gas used to pre-reduce the manganese; fuel is burned to produce process steam; and coke and electrical energy are used in the reductive smelting of the nodules and the electrochemical reduction of the other metals.

The base-case process description is based on the use of coal as a primary energy source, with minimum cogeneration of power on site. This configuration was chosen to utilize a low-cost fuel, coal, and to minimize the total capital requirements of the plant. However, other combinations might be considered in response to site-specific economic and environmental factors. For example, if power is relatively expensive, all necessary power can be cogenerated on site, although costs would be increased in the plant services area. Or, if local problems with air quality prohibit the use of coal as a primary fuel, oil (or even natural gas) could be substituted. In this case, capital costs would decrease because coal-handling costs are eliminated, but operating costs would increase because oil is more expensive than coal.

The final choice of plant configurations, then, is dictated by the relative costs of the fuels, purchased power costs, required returns on invested capital, and environmental considerations.

<u>Process Electric Power</u>

The cost of electric power in quantities needed for the four-metal smelting plant varies widely in the western United States. Utility companies in southern California quoted various rates equivalent to almost 11 cents per kilowatt-hour; the Pacific Northwest rates were only 3 cents per kilowatt-hour, 27 percent of those in southern California, which were used in the base case.

The process plant must include at the minimum some on-site fuel combustion to generate steam for internal process use and in that combustion also can easily generate some electricity proportional to the amount of steam required, defined as the minimum cogeneration level. Higher temperature and pressure steam is produced in more efficient boilers and let down through an electrical generation turbine to the condition needed for use in the process. The steam turbine generates electricity for very little more cost than needed for the steam alone at the desired flow rate, temperature and pressure. However if more electricity is to be generated at the site of the processing plant, a much larger investment in boilers, turbine-generators, water supply, and fuels is needed. Given the increased capital and operating costs, increased cogeneration may be about intermediate in expense between buying power in southern California and the Pacific Northwest, no matter what fuel (coal or oil) is utilized.

For the base four-metal smelting case, electricity purchased at 11 cents per kilowatt-hour was supplemented by minimum cogeneration of electricity with coal, a low-cost fuel that probably would not be approved at present because of pollution control regulations. Fuel oil can also be used at either location for minimal or total power generation. Coal costs were assumed to be $50 per ton ($2.20 per million Btu). Residual fuel oil at 83 cents per gallon ($34.70 per barrel, delivered) is substantially more expensive ($5.50 per million Btu) but would reduce permitting problems.

Plant descriptions, revised material and energy balances, and costs estimates have been prepared for the following energy-use alternatives:

Base Case	Use of coal, minimum cogeneration of power.
Case 1	Use of oil, minimum cogeneration of power.
Case 2	Use of coal, total power generation on site.
Case 3	Use of oil, total power generation on site.

Capital Costs

Capital costs for these alternatives were estimated with the same factoring technique used to develop the base-case costs. Costs were attributed to all items of equipment added, deleted or modified by the change in energy mix in the materials handling and plant services subsectors. The cost changes were summarized, and the appropriate factors for installation, purchased commodities and indirect costs were used to determine the revised fixed capital requirements.

The total capital requirements for Sector 6 are summarized below in 1982 U.S. dollars:

Case	Total Fixed Capital Cost ($ millions)
Base - minimum coal cogeneration	506.0
1 - minimum oil cogeneration	467.0
2 - maximum coal cogeneration	616.0
3 - maximum oil cogeneration	549.0

Annual Operating Costs

Annual direct operating costs were estimated for the alternatives from the material and energy balance and capital cost estimate appropriate for each. Revised estimates of fuel and power consumptions were prepared, fixed costs were re-estimated for the revised capital costs, and the labor profile was revised as required. Operating costs were estimated for plants located in areas where purchased power costs are relatively high at 11 cents per kilowatt-hour (southern California) and relatively low at 3 cents per kilowatt-hour (Pacific Northwest). Other sector costs are assumed to be the same as in the base case.

Annual operating costs are summarized below for all cases in each location:

Case	Total Annual Operating Cost, Sector 6 ($ million/year)		
	3¢ Power	7¢ Power	11¢ Power
Base - minimum coal cogeneration	167.0	210.0	253.0
1 - minimum oil cogeneration	178.0	216.0	253.0
2 - maximum coal cogeneration	175.0	175.0	175.0
3 - maximum oil cogeneration	223.0	223.0	223.0

All of the other base-case costs are unchanged for these alternative energy mix evaluations.

Pacific Northwest Plant Location

One alternative to avoid the high cost of electric power in southern California of 11 cents per kilowatt-hour is to locate the four-metal smelting plant in the Pacific Northwest. With electricity purchased at 3 cents per kilowatt-hour, generation of any electricity onsite (whether by coal, oil or gas) is more expensive than purchase. Therefore, minimum cogeneration (with process steam) is assumed, with coal as fuel. Lower hydroelectric power costs, and possible cost savings in land, pollution control, construction permitting and other elements, make this prospect intriguing. Extra costs for longer transportation of nodules to the Pacific Northwest are shown in Table 8. A pair of larger transport ships, about 75,000 DWT each, would be needed to maintain the mining rate. Therefore, a larger unloading berth is needed. The mining and processing sectors are unchanged in this alternative, a conservative assumption with regard to the potential savings mentioned above.

Cost data for this alternative are shown in Table 8.

Table 8. Summary of Sectors and Costs for Pacific Northwest, Four-Metal Plant (millions of 1982 dollars)

Sector	Item	Capital Cost	Operating Cost
1	R&D, P&E	0	6.0
2	Mining	180.0	39.1
3	Ore Marine Transport	130.0	17.5
4	Ore Marine Terminal	34.1	3.6
5	Onshore Transport	26.5	4.3
6	Processing	506.0	164.0
7	Onshore Waste Disposal	5.6	1.1
8	Support/G&A	1.6	9.0
	Total	883.8	244.6
	Preparatory Expense	195.0	
	Continuing Expense	178.0	
	Working Capital	190.0	
	Total Funding	1,446.8	

Shallow Ports

If U.S. ports are not deepened to at least 45 feet at low water, several additional costs will be incurred to transport nodules into shallower depth ocean ports. These additional costs for the operator could arise in several different forms.

If more, but smaller, transport ships are used, the unit transportation costs will increase because of the diseconomies of small scale from adding an extra ship to the fleet with another crew. Other problems include potential queues at both the mining ship and the ore terminal, less productivity in the load-and-discharge cycles because of the slower average transfer rates, and higher fuel consumption per ton of nodules. Using the 1977 report data [2], a reduction of port depth to 39 feet increases transport costs by 34 percent even if the ships are carefully matched to the traffic tonnage and complications are minimized. Although the mining ship may be smaller with less nodule stowage capacity, larger size is still desirable -- up to some economic limit -- to assure continued production and for stability.

Another alternative would be to use the desired size nodule transports, and transfer nodules and fuel to and from barges at a deepwater location outside the port terminal. In southern California, offshore weather is generally favorable for this transfer if the barges are large enough. A separate vessel to carry cargo-handling gear for discharging the transports' loads into nodule barges bound for a shallow terminal may be more cost-effective than equipping transfer barges or ships. Alternative cargo handling methods include slurry discharge, cranes with buckets and continuous catenary unloaders. Ship discharge rates by vessel-mounted equipment would not be able to maintain transfer rates comparable to the shore-based facilities because of the limited equipment capacity, the need to move barges and to reposition the unloaders, greater weather effects, and difficult access for maintenance and operation.

For the southern California case, if a four-barge transfer is selected, and each carries one load per ship call, each barge would have about 18,500 DWT, and a 20- to 25-foot draft, the specific design depending on sea conditions and handling method. The barges could be discharged by shore-mounted slurry pumps, bucket cranes and conveyor, or wheel reclaimers, at a slightly slower rate than the ship discharge to barge gear.

This system, with double handling of the nodules, double handling gear, and the cost of additional barges, will be more expensive. The cost estimates in Table 9 are very rough, illustrate only the magnitude of the impact, and are not part of an optimization scheme. These rough estimates assume use of a single or double continuous bucket unloader mounted on a large anchored barge, with dry conveyor transfer to four covered hopper barges in turn. One tug boat positions all the barges. A relatively shallow barge-unloading pier carries a bucket wheel unloader to empty nodules onto a conveyor to the ponds for loading the slurry pipeline to the plant. The sizes and costs are noted in Table 9 for southern California and Pacific Northwest terminals. Because the barge transshipment times to unload the transports should be about the same (because some port entry and exit times are reduced), the same size and costs of nodule transport ship may be used for each case as a preliminary estimate.

Table 9. Shallow Depth Port System (3 million wet S.T.p.a., 1982 costs in millions)

Location	Southern California Size	Southern California Costs Capital	Southern California Costs Operating	Pacific Northwest Size	Pacific Northwest Costs Capital	Pacific Northwest Costs Operating
Transport Ship DWT	61,000			75,000		
Transhipment Pontoon						
Rate, tph	2,000			2,700		
CB Unloader Cost		$7.5	$2.5		$9.2	$2.4
Pontoon DWT	8,00			11,000		
Pontoon LxBxD, ft	315x83x19			360x95x20½		
Pontoon Cost		$4.3	$0.4		$5.7	$0.5
Transfer Barges - 4						
Barge DWT, each	18,500			22,500		
Barge cost, each		$9.8	$1.1		$11.5	$1.3
Tug BHP	4,600			5,500		
Tug Cost - one		$4.4	$1.7		$5.2	$1.8
Barge Pier						
Length x depth, ft	470x17¼			545x18.2		
Pier and Dredging		$1.87	$0.08		$2.3	$0.11
Handling Equipment						
Barge Unloader, conveyor, stacker & storage		$8.2	$1.33		$9.4	$1.69
Total Terminal Costs*		$70.5	$7.54		$80.6	$8.22
Comparable Direct Ship Call Terminal Costs		$30.5	$3.86		$34.1	$3.60
Extra Cost per Wet Ton, 20 years		67¢	$1.227		77.5¢	$1.54

*Includes 11 acre site and 30,000 ft^2 building at $0.7 and $1.2 million dollars respectively in both sites for capital costs and $0.317 or $0.105 million for operating costs.

Table 9 indicates that the double handling needed between large nodule transport ships and smaller barges more than doubles the terminal and handling costs and essentially adds direct costs of $2 to more than $3 per ton of wet nodules handled. $80 million could be better spent over the project life on port channel dredging for the benefit of all ocean shipping, rather than this amount for nodules alone.

Table 10 summarizes the capital and operating costs for this alternative in southern California.

Table 10. Summary of Sectors and Costs for Shallow Ports, Southern California (millions of 1982 dollars)

Sector	Item	Capital Cost	Operating Cost
1	R&D, P&E	$ 0.0	$ 6.0
2	Mining	180.0	39.1
3	Ore Marine Transport	119.0	15.4
4	Ore Marine Terminal	70.5	7.5
5	Onshore Transport	26.6	8.3
6	Processing	506.0	253.0
7	Onshore Waste Disposal	5.6	1.1
8	Support/G&A	1.6	9.0
	Totals	$909.3	$339.4

European Ship Chartering

An alternative to American transport ship construction and operation is to charter European-built and manned vessels. This same analysis was performed in detail for the 1980 analysis of three-metal plants [17]. Therefore the overall cost ratios developed were applied to the 1982 estimated costs for American ships, as follows, in millions of dollars:

1982 U.S. Cost		1980 Ratio	Estimated 1982 European Cost
Capital	$119.2	1.914	$62.2
Equivalent Bareboat Charter Hire			7.47
Operating	9.06	1.235	7.34
Fuel	6.16	N.A.	6.16
Total Cost			$21.0

The base-case summary costs are therefore altered only in Sector 3; deleting the $119 million capital cost and substituting zero, and replacing the $15.4 million operating cost with $21.0 for charter, plus $0.21 million for helicopters gives a total of $21.2 million.

Alternative Construction Periods

Under some circumstances, a shorter construction period than that assumed in the base case could be achieved with fast-track designs and construction methods, expedited approval of permits, a prompt ordering of custom machinery for the process plant, terminals and ships. Rather than six years, as in the base case, a greatly accelerated schedule of four years, including six months of debugging and trial operations as before, has been evaluated to review the impact on the project returns. The sector construction costs spread in the base case over Years 1 and 2 (including land) were all folded into the cost of Year 3, and no costs are shown for Years 1 and 2 under this alternative computation by the Payout Model. The total sector costs are unchanged under this plan.

In the base case, prompt startup of the plant after construction is assumed. Reasons for possible delay in starting after plan completion include process failures, labor negotiations and, especially in certain regions, delays in receiving the multitude of permits from

Federal, state and local officials. Some of the at-sea permit problems are described in Section IV.

To evaluate how such delays might affect payout, delays as long as four years can be specified in one-year increments after completion of the plant in Year 6, extending the evaluation period to as long as 30 years. For each year of delay, a flat cost can also be input, and for this analysis, $200 million per annum is treated as the only expense during each year of delay.

The Three-Metal Process

The prior analysis [17] examined the pioneer deep ocean mining venture producing only three primary metals; nickel, copper and cobalt. Because costs were estimated in 1980 they are updated here to facilitate direct comparison, and in the following text, addition of a process to obtain manganese from this three-metal plant rejects is evaluated.

Three-Metal Process Descriptions

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

For the nodules, 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 are reduced in a fluid bed roaster and cooled in water sprays before 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, the nodules are quenched in tanks of recycled ammonia leach liquor, pumped as slurries 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 valuable metals are separated from each other by selectively extracting the dissolved metals from the aqueous solution with 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.

Next, the valuable reagents and metals are washed out of the by-products of various operations and the reagents prepared for recycling. The tailings of slurry is washed of its residual metals in a five-stage counter-current decantation unit. Barren tailings from this washing are steam-stripped of their ammonia reagents in a stripping tower and then prepared for disposal. Ammonium sulfate is reacted with slaked 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 last steps of the process produce marketable metals and materials from the products of the metals separation steps. Most of the nickel is recovered by electrowinning, including 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 by electrowinning, including stripper and commercial cells, facilities for starter sheet preparation and nickel removal, and necessary electrical equipment. Cobalt is removed from the raffinate liquor by precipitation with hydrogen sulfide and is then recovered, along with nickel powder and copper/zinc sulfides, by selective leaching and hydrogen reduction. This section includes sintering and packaging machines along with numerous reactor and separation vessels and necessary tankage. Recovery efficiency of 94 percent for nickel and copper and 70 percent for cobalt are expected. Secondary metal recoveries of 3 percent of primary metal value are assumed.

Included in the plant 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.

Three-Metal Plant Costs

The costs of the hydrometallurgical three-metal plant and system described in reference [17] are updated to 1982 dollars in Table 11.

Table 11. Summary of Sectors and Costs for Three-Metal Plant of 3 Million s. tons Annually (millions of 1982 dollars)

Sector	Item	Capital Cost	Operating Cost
1	R&D, P&E	0	6.0
2	Mining	345.0	82.3
3	Ore Marine Transport	132.0	24.8
4	Ore Marine Terminal	33.7	4.3
5	Onshore Transport	45.0	11.9
6	Processing	502.0	117.0
7	Onshore Waste Disposal	25.4	7.8
8	Support / G&A	1.6	6.3
	Totals	1,084.7	260.4
	Preparatory Expense	195.0	
	Continuing Expenses	139.0	
	Working Capital	155.0	
	Total Investment	1,573.7	

This plant has twice the throughput of the four-metal plant previously described in this report.

Recovery of Manganese From Three-Metal Process Rejects

In contrast to manganese recovery from raw nodules, manganese is recovered from three-metal process rejects by a simple physical separation technique [28]. A process description and material and energy balance for this processing option were developed to estimate the capital and operating costs involved. In the following description, the manganese recovery plant would be designed into a three-metal processing plant described previously with a throughput of three million dry tons of nodules per year. The recovery plant is large enough to accept all of the rejects, but processing at less than full rate for manganese recovery would be optional. In such a configuration, necessary services would be supplied by expanding those required for the three-metal plant alone, rather than building separate facilities.

Added Process

For the added, fourth metal process, rejects from the three-metal plants' ammonia recovery stripper would be cooled, flotation recovery reagents added, the pH adjusted by acid addition, and the pulp density adjusted to the desired range. The conditioned pulp then passes to a conventional flotation circuit consisting of rougher, scavenger, and cleaner cells. The manganese-depleted tailings pass to a neutralization step, and then to disposal in tailings ponds. The flotation concentrate is thickened and filtered to produce a relatively pure wet manganese carbonate cake. The solids are then partially dried by direct contact with combustion gases, a suitable binder is added, and the mixture is pelletized and dried further. The pellets containing manganese carbonate are heated, and the carbonate is converted to manganese oxide (calcine) by contact with combustion gases under reducing conditions. The calcine then passes to smelting for recovery of manganese.

Because a relatively high-grade manganese carbonate can be produced in the flotation step, a commercially acceptable high-carbon ferromanganese product can be produced in one smelting step. The calcine is charged to electric furnaces along with coke for reduction, lime and trim amounts of iron for obtaining the desired slag composition, and sized revert materials. Product ferromanganese is tapped from the furnance for casting and sale, and slag -- which contains the clay-like impurity material from the flotation cake -- is skimmed and transferred to a second electric furnace smelting operation. Here, additional coke and fluxes are added and the slag is reduced further. The products of this reduction are a high-carbon silico-manganese product, which is tapped for casting and sale, and a slag that contains little manganese and is then granulated and disposed of.

Recovery of manganese from three-metal process rejects requires additional materials handling facilities to receive, store and distribute the additional amounts of materials, supplies and fuels consumed in the process. In addition, the service facilities must be designed to provide the increased amount of combustion gases, power and cooling water required. Also, the amount and nature of process wastes produced will be reduced and changed. Significant amounts of inert slag will be generated, which can be disposed of at a properly prepared site adjacent to the plant. But the amount of more difficult-to-dispose-of tailings will be halved, and so the size of the transportation pipeline and disposal area for tailings can be reduced.

Capital Costs

Fixed capital requirements for a processing system in which manganese is recovered from the rejects from a three-metal process plant were developed by the same factoring techniques used to derive costs for other process sectors. In addition to estimating the costs of the new plant sectors required, it was also necessary to reestimate the costs of those sectors of the three-metal plant that would be changed by adoption of the manganese recovery option.

The processing sector capital costs for the recovery of four metals (nickel, copper and cobalt in a "three-metals" plant with manganese recovered from rejects) are summarized below by subsector. These 1982 costs are for the treatment of three million tons of nodules per year with maximum recovery of manganese.

Sector 6 Item	Capital Cost (millions of 1982 dollars)
Materials storage, handling and preparation	$125.9
Nodules reduction and metal extraction	63.2
Metals separation	51.9
Reagent recovery and purification	59.7
Cu/Ni/Co recovery and purification	110.1
Manganese carbonate flotation, drying and reduction	52.8
Ferro-manganese reduction	73.7
Silico-manganese reduction	32.7
Off-gas handling and fugitives control	30.0
Smelting support services	56.7
Plant services	144.8
Land	1.5
Total	$803.0

The costs reductions in the pipeline and tailings disposal area for tailings and the costs for construction of a new slag disposal area were also estimated. These alternative Sector 5 and 7 capital costs, summarized below, cover the same accounts presented in the base-case analyses: Sector 5 costs include the pipelines and pumping stations and land, and Sector 7 costs include the construction of the first three years' disposal areas.

	1982 Capital Cost
Sector 5 Costs (Onshore Transportation)	$42.7 million
Sector 7 Costs (Waste Disposal)	$14.2 million

Costs in other sectors of the pioneer venture would not be changed if manganese were recovered from three-metal process rejects.

Annual Operating Costs

Annual direct operating costs for a processing system in which manganese is recovered from the rejects from a three-metal process plant were developed from the revised material and energy balances, capital cost estimate and a revised staffing estimate. These costs are summarized below by category for the entire process plant, i.e., for the production of four metals from three million tons of nodules per year.

Sector 6 Item	Annual Operating Cost (million 1982 dollars)
Materials and supplies	$ 33.2
Fuels and Water	102.4
Power at 11 cents per kilowatt-hour	208.5
Labor	26.8
Fixed Charges	59.1
Total	$430.0

The annual direct operating costs for operation of the waste disposal pipeline and tailings and slag disposal areas have also been re-estimated. The estimating method used and the accounts covered are the same as for the base-case estimates. These operating costs are summarized below in 1982 dollars.

Sector 5 Costs (Onshore Transportation)	$11.1 million/year
Sector 7 Costs (Waste Disposal)	$ 3.5 million/year

Annual operating costs in the other sectors would remain unchanged for this added fourth metal to a three million dry short tons per annum, three-metal processing plant.

Total System Costs

Table 12 summarizes the capital and operating costs of three million dry short tons per year plant producing hydrometallurgical copper, cobalt and nickel, and smelting manganese.

Table 12. Summary of Sectors and Costs for Three-Metal plus Manganese Plant, 3 Million s.t.p.a. (millions of 1982 dollars)

Sector	Item	Capital Cost	Operating Costs
1	R&D, P&E	$ 0	$ 6.0
2	Mining	345.0	82.3
3	Ore Marine Transport	132.0	24.8
4	Ore Marine Terminal	33.7	4.3
5	Onshore Transport	45.0	11.9
6	Processing	802.0	430.0
7	Onshore Waste Disposal	10.4	2.8
8	Support/G&A	1.6	6.3
	Totals	$1,369.7	$568.4
	Preparatory Expenses	195.0	
	Continuing Expenses	139.0	
	Working Capital	339.0	
	Total Investment	$2,042.7	

III

PAYOUT ANALYSIS

As mentioned in the Introduction, the Texas A&M University Payout Model required modification to reflect the provisions of the Tax Equity and Fiscal Responsibility Act of 1982 (1982 TE & FR Act). The Payout model was based upon that described in [17], which included the 1981 Economic Recovery Tax Act, for the three-metal case, but was rewritten to:

1. Calculate the percentage of capital expenditures in each year for each sector during the construction phase, substantially simplifying input;
2. Accommodate an extended delay between completion of the construction and test phase, and the beginning of productive mining and processing;
3. Present better cash flows and tax computations during the life of the project, accommodating revised investment tax credits, tax loss carry-forwards, depreciation and interest; and
4. Provide for long-term debt on the fixed plant at various levels and interest rates.

Basic Approach

The authors' industrial experience in the shipbuilding, minerals processing, and ocean resource development businesses strongly influenced the approach to this Payout Analysis technique. Most payout calculations are performed in industry to assist the corporate directors and top management in making investment decisions among competing proposals. Hence, as long as the same formula is used for all projects under consideration, the relative merits can be fairly judged IF (a large if), the cost and revenue estimates are accurate. Estimating costs precisely is far more difficult than computing rates of return. The historic low interest rates in the United States from the 1930's until the early 1970's encouraged comparison to be made on the "simple average return," "capital recovery factors," or "pay-back period" values, both before and after taxes. With higher interest rates, the real-time cost of the monies invested also become important, resulting in the comparisons by use of Internal Rate of Return (IROR), also called Discounted Cash Flow Return (DCFR), both before and after taxes.

Another industry influence reflected in this Payout approach is the emphasis on cash flow, with its attention to full and early use of all tax shelters available to the independent entity. The Tax Equity and Fiscal Responsibility Tax Act of 1982 was passed during this research effort, resulting in, for example, a major revision of the tax carryforward schedules and some improvement of the computed returns.

The pioneer venture is analyzed here as a stand-alone enterprise, that is, an independent entity where all monies are invested in the corporation and all tax benefits come to it. This is unlike most actual practices, in which the consortium members are in partnership, and the expenditures of the joint venture flow back to the partners as both cash expenditures and tax deductions. Therefore, this stand-alone venture cannot benefit from immediate tax writeoffs.

The limiting assumptions in the base case, relaxed in some of the alternatives computed, include:

1. The program is a technical and management success.
2. Cost escalation is offset by increases in metal prices (revenues).
3. All equipment functions for the 20-year operating life of the project, with necessary replacements provided for as maintenance and repair in annual operating costs.
4. Payments of 0.75 percent of gross revenues to an escrow account are made under Public Law 96-283.
5. The first six months of operations of the entire system are funded as part of the system test (in Year 6).
6. Revenues in the first year of full production are 80 percent of all subsequent annual revenues, but operating costs are not reduced.
7. Straightline depreciation is used as the five-year depreciation life, or the alternate ACRS schedule, for all capital equipment and fully protects earnings from taxes until this shelter is fully utilized.
8. The full investment tax credit (ITC) is taken, reducing depreciation by half of the ITC.
9. R&D and P&E costs accumulated before the GO/NO GO decision are expensed and included as a negative cash flow in Year 1. As alternatives, these preparatory expenses can be amortized over the plant life, or sunk.
10. All working capital, and land at cost, are recaptured in the last year of the program.

11. The capital and operating costs of any regulatory regime are zero. The costs of monitoring described in this report do not discernibly affect returns.
12. The salvage value of the plant and equipment is equal to the cleanup costs.
13. The program will not be unduly delayed by the regulatory and permitting process. This assumption is evaluated later in this report.
14. No depletion allowances are claimed, but the effect of depletion can be examined through a reduction of the effective tax rate, which was examined.
15. Metal prices are "normal" rather than artificially high (as when cobalt was at $20 per lb) or low (e.g., copper at 65 cents per lb). Prices are considered later as a variable.
16. A 46 percent tax burden (when applicable) is used with no modification for small initial earnings. Other tax rates are also evaluated for the sensitivity of the return to the base case assumption.
17. No debt (or leverage) is used in the base case, but a case with debt at various interest rates was examined later.

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

The Computer Program

The flow chart for the Deep Ocean Mining Payout Program is shown as Figure 3. The inputs are described briefly in the following paragraphs,

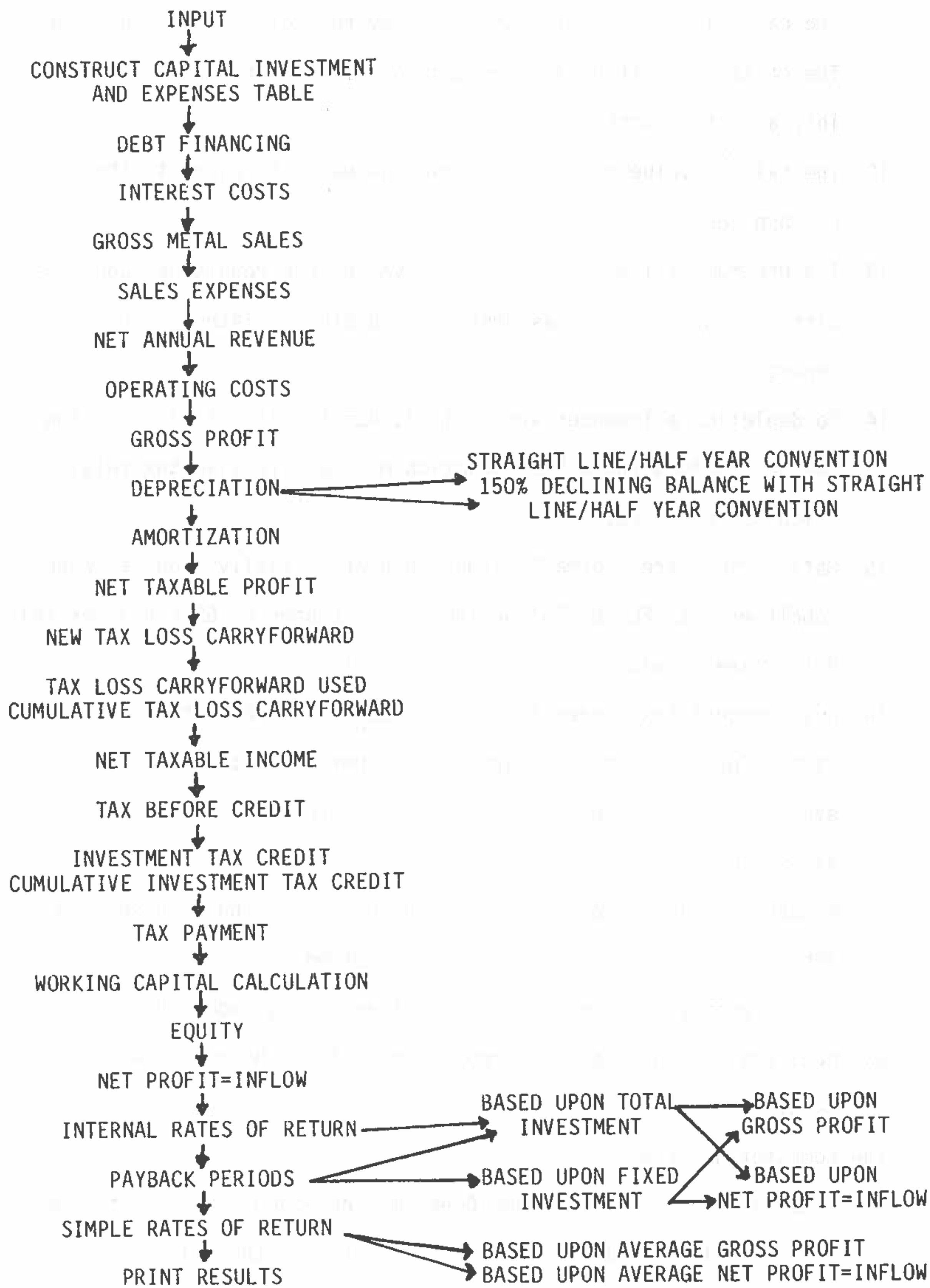


Figure 3. Deep Ocean Mining Payout - Flow Chart

and the outputs are shown later. The sequence of computations outlined in Figure 3 are described in detail in the Appendix A. Several general notes are relevant here. The capital cost expenditure matrix, by year, is computed first from the input sector costs data, and the program includes arbitrary percentages of expenditure by sector in each of the first six years. Then total investment is summed for each year, as are expensible items during the six-year construction period. The net result is a matrix which is presented as Page 2 of the results, shown on Page 83 of this report.

Operating costs, revenues and tax deductions during the 20-year production life are computed for each appropriate year and are also inserted into the discounting matrix, and later printed out on Pages 3 through 7. Depreciation can be either taken ACRS Schedule over five years, or a straight line over any specified term, with a half-year convention. ACRS provides a fixed schedule at 150 percent declining balance, which assumes one-half year depreciation the first year (15 percent), followed by one year at 22 percent, and three at 21 percent each, based upon unadjusted basis and no salvage value. In the first year of production (Year 7), the product value is reduced by 20 percent to reflect normal startup problems. Amortization of preparatory expenditures over the project useful life can be reported here, if neither expensed in year one, nor ignored.

Then the cash flow, tax payments and working capital are computed, including the carry-forwards up to 15 years of both depreciation and investment tax credit.

As the last step, the average returns over the 20-year production period, payback time periods and discounted internal rates of return are computed, both before and after taxes.

The computer program prepared and utilized this year is described in detail in Appendix A, separately bound as a "Users Manual." The program may be leased from Texas A&M University. The salient features of the program are described here. There are two current programs, the October 1982 edition, which was based upon the 1981 Payout Model described in [17], and the November 1982 edition, which also includes provisions for analysis of debt financing and otherwise is exactly the same as the October version. Both programs reflect the provisions of the 1981 Economic Recovery Tax Act and the 1982 Tax Equity and Fiscal Responsibility Act, and delete the portions of the Tax Code that apply to pre-1982 investments, because none is reasonable for deep ocean mining ventures. Therefore, much of the depreciation classification programming for different life equipment has been deleted, because all equipment now has a five-year depreciation period for federal taxes.

The programs now stands as a simple batch program for remote terminal operation on the Texas A&M University Data Processing Center's AMDAHL 470V-6 computer, which utilizes "WYLBUR," a FORTRAN IV language. The program may be leased from Texas A&M University, and may be used without modification within these strict limits: no more than 30 years of evaluation period; inputs as described below; and taxation appropriate only under the 1982 Tax Equity and Fiscal Responsibility Act. Each case requires now only 0.2 second of execution time, because the computations of the discounting rate of return have been materially accelerated.

Input and Options

Figure 4 is the input data sheet for use on the keyboard operation. The first six sections of the form are used for both October and November program sessions; Section 7 is used only for the debt input in the November program.

Figure 4 has the input data completed for the base case, and illustrates the use of the input data format. Each variable name is a shorthand description of the sector, with its number. All the capital and operating costs are entered in thousands of dollars in Sections 1, 2 and 4. In Section 3, prices of metals are entered in dollars per pound, recovery efficiencies in decimals, assays in percentage of each of the four metals in the nodule ore, and annual production in short tons. In Section 4, the degree of cogeneration, the preparatory expense, and the year of expensing the "preparatory" amount is also specified. In Section 5, the years of delay are entered and the delay cost per year of delay, in thousands of dollars. In Section 6 the depreciation method (straightline or schedule), number of years, and the tax rate are entered as a decimal.

For the debt cases, Section 7 entries are, in order, the percentage of fixed capital investment to be financed, the annual rate of interest, the method of repayment (1 for level repayment principal, plus declining interest; 2 for level principal plus interest payment), the year of start of repayment, and year to finish debt repayment, both by number of year in this analysis.

Final Base Case
So. Cal. Smelting, 11¢/Kw
Energy Case 0=min. Coal Cogen.

1. TOTAL CAPITAL COSTS FOR EACH SECTOR BY NUMBER, INCLUDING LAND:

Prospecting & Exploration	Mining	Ore Marine Transportation
PAE1CC=0.	MIN2CC-180000.	TRA3CC=1190000.
Ore Marine Terminal	Onshore Transportation	Processing
PRT4CC=30500.	SHR5CC=26600.	PRO6CC=506000.
Waste Disposal	Additional Support/G&A	
DIS7CC=5600.	SUP8CC=1600.	

2. TOTAL ANNUAL OPERATING COSTS FOR EACH SECTOR BY NUMBER

Prospecting & Exploration	Mining	Ore Marine Transportation
SECT(1)=6000.	SECT(2)=39100.	SECT(3)=15400.
Ore Marine Terminal	Onshore Transportation	Processing
SECT(4)=3900.	SECT(5)=8300.	SECT(6)=253000.
Waste Disposal	Additional Support/G&A	
SECT(7)=1100.	SECT(8)=9000.	

3. METAL PRICES, PROCESS EFFICIENCY AND NODULE ASSAY, 4 METALS, AND ANNUAL PRODUCTION

Nickel Price	Cobalt Price	Copper Price	Manganese Price
PRINI=3.75	PRICO=5.50	PRICU=1.25	PRIMN=0.40
Nickel Efficiency	Cobalt Efficiency	Copper Efficiency	Manganese Efficiency
EFFNI=.95	EFFCO=.85	EFFCU=.95	EFFMN=.93
Nickel Assay	Cobalt Assay	Copper Assay	Manganese Assay
ASSYNI=1.30	ASSYCO=0.25	ASSYCU=1.10	ASSYMN=2910

Annual Nodule Production
ANPRD=1500000.

1% Secondary Metal Reenues

4. COGENERATION, PROSPECTING AND EXPLORATION, AND EXPENSES

Cogeneration Alternative	Preparatory Period Expenditures	Preparatory Period Expenditures Expensing Method	Continuing Expenses
COGEN-1.	PPEXP-195000.	MPPEXP=1	SECCAP=178000.

Figure 4. Input Data Sheet for Deep Ocean Mining Payout Analysis on WYLBUR

5. PRE-PRODUCTION DELAY AND ANNUAL COST

Delay Length	Annual Delay Cost
MDELAY=0	DECOST=0.

6. DEPRECIATION AND TAX RATE

Depreciation Method	Profits Tax Rate	Depreciation Length
IDEPR=2(SL)	TXRATE=.46	MDEPR=5

7. DEBT FINANCING METHOD

Debt Percentage	Interest Rate	Repayment Method	Initial Repayment Year	Final Repayment Year
DETPER=0.1	RATINT=0.	MREPAY=1	MSTART=0	MFINIS=0

Figure 4. Concluded.

The present program has built-in distributions for the timing of the capital outlays over the fixed six-year investment (pre-production) analysis period. Changes in this cost distribution require changes to the program, a small job with the remote terminal operation, and this was used only once in the evaluation of the accelerated construction schedule.

User options include (a) depreciation time for straightline, or ACRS; (b) timing of the tax deduction for preparatory period expenses; (c) addition of an integral number of years delay and an annual delay cost; and (d) debt financing as a percentage of fixed plant cost, at an interest rate to be specified, using either level debt service or level principal prepayment with declining interest, and specifying the years of debt repayment.

The Base Case

A major objective of this research was to define accurately and to document an estimate of the capital and annual operating costs of a practical four-metal, pioneer deep ocean mining venture. This four-metal base case, as described in Section II, produces manganese in addition to copper, nickel and cobalt and assumes that, because of the large market share of the manganese product and the cost of the plant, throughput is limited to 1.5 million short tons of nodules annually. This rate is one-half the size of the three-metal system analyzed in [17].

The computer outputs for the base case are shown on the following eight pages as Table 13. The complete computer printout includes not

Table 13. Texas A&M University, Ocean Engineering Program Deep Ocean Mining Payout Analysis, October 1982

```
PAE1CC=      O.      MIN2CC= 180000.     TRA3CC= 119000.
PRT4CC=   30500.     SHR5CC=  26600.     PRO6CC= 506000.
DIS7CC=    5600.     SUP8CC=   1600.

SECT(1)=   6000.     SECT(2)= 39100.     SECT(3)= 15400.
SECT(4)=   3900.     SECT(5)=  8300.     SECT(6)=253000.
SECT(7)=   1100.     SECT(8)=  9000.

PRINI= 3.75$/LB      PRICO= 5.50$/LB     PRICU= 1.25$/LB     PRIMN= 0.40$/LB
EFFNI=0.950          EFFCO=0.850         EFFCU=0.950         EFFMN=0.930
ASSYNI= 1.30%        ASSYCO= 0.25%       ASSYCU= 1.10%       ASSYMN=29.00%
ANPRD=  1500000. SHORT DRY TONS PER YEAR

WKCAP= 184000.       PPEXP= 195000.      SECCAP= 178000.

THE PREPARATORY EXPENSES ARE PLACED IN YR 1

O YR DELAY WITH      O. ANNUAL DELAY COST
STRAIGHT LINE HALF YEAR CONVENTION OVER  5 YEARS
TAXRATE=0.460
MINIMUM COGENERATION- 28% SECT(6) OPERATING COST
```

Table 13. Continued

CAPITAL INVESTMENT AND EXPENSES

1982 DOLLARS X 1000
BY YR OF CAPITAL BUILDUP

CAPITAL ITEMS	1	2	3	4	5	6	LAND	TOTAL
PROSP AND EXPLOR	0.	0.	0.	0.	0.	0.	0.	0.
MINING	4104.	6102.	23202.	36648.	61074.	48870.	0.	180000.
MARINE TRANS.	0.	0.	0.	23871.	61035.	34093.	0.	119000.
PORT TERMINAL	0.	5493.	8336.	8336.	8336.	0.	0.	30500.
SHORE TRANS.	2713.	0.	3346.	7794.	6756.	2304.	3687.	26600.
PROCESSING	0.	44073.	121238.	143299.	132268.	64161.	961.	506000.
WASTE DISPOSAL	0.	0.	0.	233.	3275.	1825.	267.	5600.
ADD. SUPPORT	0.	0.	0.	0.	0.	1600.	0.	1600.
TOTAL DEPRECIABLE WITH LAND	6817.	55668.	156121.	220181.	272745.	152853.	4915.	869300.
TOTAL FIXED INVESTMENT WITH LAND IN YR 1	11732.	55668.	156121.	220181.	272745.	152853.	0.	869299.
CONTINUING EXPENSES	14105.	14105.	14105.	14105.	14105.	107476.	0.	178000.
WORKING CAPITAL						184000.		184000.
PREPARATORY PERIOD EXPENSE	195000.							195000.
TOTAL FUNDING INVESTED (LAND IN YR 1)	220837.	69772.	170226.	234286.	286850.	444329.	0.	1426299.

Table 13. Continued

CASH FLOWS AND TAXES BY YEAR OF PROJECT

		YR1	YR2	YR3	YR4	YR5	YR6
		-----	-----	-----	-----	-----	-----
	CAPITALIZED INVESTMENT= OUTFLOW	11732.	55668.	156121.	220181.	272745.	336853.
CASH	GROSS METAL SALES	0.	0.	0.	0.	0.	0.
FLOWS	SALES EXPENSES	0.	0.	0.	0.	0.	0.
	NET ANNUAL REVENUE	0.	0.	0.	0.	0.	0.
	OPERATING COSTS	209105.	14105.	14105.	14105.	14105.	107476.
	GROSS PROFIT	-209105.	-14105.	-14105.	-14105.	-14105.	-107476.
	TAX PAYMENT(BELOW)	0.	0.	0.	0.	0.	0.
	NET PROFIT= INFLOW	-209105.	-14105.	-14105.	-14105.	-14105.	-107476.
TAXES	GROSS PROFIT	-209105.	-14105.	-14105.	-14105.	-14105.	-107476.
	DEPRECIATION	0.	0.	0.	0.	0.	0.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	NET TAXABLE PROFIT	-209105.	-14105.	-14105.	-14105.	-14105.	-107476.
	NEW TAX LOSS CARRYFORWARD	209105.	14105.	14105.	14105.	14105.	107476.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	0.	0.	0.	0.	0.	0.
	TAX BEFORE CREDIT	0.	0.	0.	0.	0.	0.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEDUCT. CARRYFORWARD	209105.	223209.	237314.	251419.	265523.	373000.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.

Table 13. Continued

CASH FLOWS AND TAXES BY YEAR OF PROJECT

		YR7	YR8	YR9	YR10	YR11	YR12
		-----	-----	-----	-----	-----	-----
CASH	GROSS METAL SALES	433756.	542195.	542195.	542195.	542195.	542195.
FLOWS	SALES EXPENSES	14097.	17621.	17621.	17621.	17621.	17621.
	NET ANNUAL REVENUE	419659.	524574.	524574.	524574.	524574.	524574.
	OPERATING COSTS	335800.	335800.	335800.	335800.	335800.	335800.
	GROSS PROFIT	83859.	188774.	188774.	188774.	188774.	188774.
	TAX PAYMENT(BELOW)	0.	0.	0.	0.	0.	0.
	NET PROFIT= INFLOW	83859.	188774.	188774.	188774.	188774.	188774.
TAXES	GROSS PROFIT	83859.	188774.	188774.	188774.	188774.	188774.
	DEPRECIATION	82117.	164233.	164233.	164233.	164233.	82117.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	NET TAXABLE PROFIT	1742.	24541.	24541.	24541.	24541.	106657.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	1742.	24541.	24541.	24541.	24541.	106657.
	NET TAXABLE INCOME	0.	0.	0.	0.	0.	0.
	TAX BEFORE CREDIT	0.	0.	0.	0.	0.	0.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEDUCT. CARRYFORWARD	371257.	346717.	322176.	297636.	273095.	166438.
	CUMULATIVE INVEST. TAX CREDIT	86439.	86439.	86439.	86439.	86439.	86439.

Table 13. Continued

CASH FLOWS AND TAXES BY YEAR OF PROJECT

		YR13	YR14	YR15	YR16	YR17	YR18
		-----	-----	-----	-----	-----	-----
CASH	GROSS METAL SALES	542195.	542195.	542195.	542195.	542195.	542195.
FLOWS	SALES EXPENSES	17621.	17621.	17621.	17621.	17621.	17621.
	NET ANNUAL REVENUE	524574.	524574.	524574.	524574.	524574.	524574.
	OPERATING COSTS	335800.	335800.	335800.	335800.	335800.	335800.
	GROSS PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	TAX PAYMENT(BELOW)	1537.	13022.	82949.	86836.	86836.	86836.
	NET PROFIT= INFLOW	187236.	175752.	105825.	101938.	101938.	101938.
TAXES	GROSS PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	DEPRECIATION	0.	0.	0.	0.	0.	0.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	NET TAXABLE PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	166438.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	22336.	188774.	188774.	188774.	188774.	188774.
	TAX BEFORE CREDIT	10275.	86836.	86836.	86836.	86836.	86836.
	INVESTMENT TAX CREDIT	8737.	73814.	3887.	0.	0.	0.
	TAX PAYMENT	1537.	13022.	82949.	86836.	86836.	86836.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	77701.	3887.	0.	0.	0.	0.

Table 13. Continued

CASH FLOWS AND TAXES BY YEAR OF PROJECT

		YR19	YR20	YR21	YR22	YR23	YR24
		-----	-----	-----	-----	-----	-----
CASH	GROSS METAL SALES	542195.	542195.	542195.	542195.	542195.	542195.
FLOWS	SALES EXPENSES	17621.	17621.	17621.	17621.	17621.	17621.
	NET ANNUAL REVENUE	524574.	524574.	524574.	524574.	524574.	524574.
	OPERATING COSTS	335800.	335800.	335800.	335800.	335800.	335800.
	GROSS PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	TAX PAYMENT(BELOW)	86836.	86836.	86836.	86836.	86836.	86836.
	NET PROFIT= INFLOW	101938.	101938.	101938.	101938.	101938.	101938.
TAXES	GROSS PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	DEPRECIATION	0.	0.	0.	0.	0.	0.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	NET TAXABLE PROFIT	188774.	188774.	188774.	188774.	188774.	188774.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	188774.	188774.	188774.	188774.	188774.	188774.
	TAX BEFORE CREDIT	86836.	86836.	86836.	86836.	86836.	86836.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	86836.	86836.	86836.	86836.	86836.	86836.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.

Table 13. Continued

CASH FLOWS AND TAXES BY YEAR OF PROJECT

		YR25	YR26
CASH FLOWS	GROSS METAL SALES	542195.	542195.
	SALES EXPENSES	17621.	17621.
	NET ANNUAL REVENUE	524574.	524574.
	OPERATING COSTS	335800.	335800.
	GROSS PROFIT	188774.	188774.
	TAX PAYMENT(BELOW)	86836.	86836.
	NET PROFIT= INFLOW	101938.	290853.
TAXES	GROSS PROFIT	188774.	188774.
	DEPRECIATION	0.	0.
	AMORTIZATION	0.	0.
	NET TAXABLE PROFIT	188774.	188774.
	NEW TAX LOSS CARRYFORWARD	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.
	NET TAXABLE INCOME	188774.	188774.
	TAX BEFORE CREDIT	86836.	86836.
	INVESTMENT TAX CREDIT	0.	0.
	TAX PAYMENT	86836.	86836.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.

NOTE: THE WORKING CAPITAL IS RECAPTURED IN THE FINAL YEAR OF OPERATION AS NET PROFIT

Table 13. Concluded

TOTAL FUNDING INVESTED= TOTAL INVESTMENT	1426299.
FIXED INVESTMENT CAPITAL REQUIREMENTS	869300.
NET ANNUAL REVENUE(GROSS MINUS SALES EXPENSES)	524574.
ANNUAL OPERATING COSTS DURING PRODUCTION	335800.
SL DEPRECIATION EXPENSE ALLOWED FOR TAXES (5 YRS)	164233.
PREPARATORY EXPENDITURES (YR 1)	195000.
BEFORE TAXES	
AVERAGE PROFIT BEFORE TAXES (20 YRS)	183528.
RETURN ON TOTAL INVESTMENT FUNDING= CAPITAL RECOVERY FACTOR	12.87%
RETURN ON FIXED INVESTMENT CAPITAL (20 YR AVERAGE)	21.11%
BEFORE TAX PAYBACK PERIOD ON TOTAL INVESTED FUNDS	14YRS 1MO
BEFORE TAX PAYBACK PERIOD ON FIXED INVESTMENT CAPITAL	11YRS 1MO
INTERNAL RATE OF RETURN (26 YRS) BEFORE TAXES	8.57%
AFTER TAXES	
AVERAGE PROFIT AFTER TAXES (20 YRS)	140338.
RETURN ON TOTAL INVESTMENT FUNDING= CAPITAL RECOVERY FACTOR	9.84%
RETURN ON FIXED INVESTMENT CAPITAL (20 YR AVERAGE)	16.14%
AFTER TAX PAYBACK PERIOD ON TOTAL INVESTED FUNDS	14YRS 4MO
AFTER TAX PAYBACK PERIOD ON FIXED INVESTMENT CAPITAL	11YRS 1MO
INTERNAL RATE OF RETURN (26 YRS) AFTER TAXES	6.41%

only the recapitulation of the input values, but also the spreading of the total sector costs over the six construction years on the second page; as well as the annual cash flows and tax calculations for discounting and the cumulative carry-forwards of tax deductions, investment tax credit, and for appropriate cases, outstanding principal amounts of loans on pages three through seven. The computer evaluation results are shown on the last page of the printout.

This section simply reports the variations made to the base case for different alternatives and sensitivity to changes in assumptions and the numerical results. The conclusions as to the significance of the computed rates of return for the base case, and for the alternative cases and the sensitivity analyses, are reported in Section IV.

The total fixed plant cost for the base case is $869 million, but the total investment of $1,432 million includes the working capital, preparatory expenditures and continuing expenses during the construction period. The average depreciable amount of $164 million annually for five years is taken because the full investment tax credit of $864 million is used.

During full production, gross annual revenues of $542 million, are reduced by sales expenses of $17 million to net sales of $426 million. Operating costs are $336 million annually during commercial production, and gross profit for Years 8 through 25 is $189 million.

Tax deductions and investment tax credit are carried forward to protect earnings fully until Year 14 from go. When depreciation and all investment tax credit is utilized, the annual tax payment for Years 16 through 26 is $89 million, leaving $102 million after tax cash inflow during those years.

The base-case, four-metal plant under the expected revenues and estimated costs and performance generates only 8.5 percent before-tax internal rate of return, and 6.4 percent after-tax IROR. The payback period is 14 years and one month on the total invested funds, pretax; and only three months longer, 14 years and four months, after-tax payback period. The payback period on the fixed investment only is 11 years and one month, the same before or after tax.

Alternative Cases

Numerous alternatives were examined to evaluate the impact of reasonable but different choices in the deep ocean mining system that have significant cost changes. Because of the large capital investment ($1.5 to $2 billion) and the annual operating cost, variations of only one percent in either capital or operating costs ($15 and $3 million, respectively) are not likely to have a sizable impact upon the rates of return -- only about 0.1 percent of after-tax rate of return. Therefore, only the largest cost factors were varied in these analyses. Those analyzed include:

(a) the three-metal base case as updated in 1982 costs for direct comparison;

(b) the same plant with additional processing of the tailings to produce salable manganese;

(c) locating the smelting four-metal plant in the Pacific Northwest to benefit from low-cost electricity;

(d) use of foreign ships;

(e) use of lightering barges at shallow ports; and

(f) shortened construction period.

Three-Metal Base Case and Same With Manganese Extraction

The prior report [17] for a system processing three million short tons of nodules annually, producing only three primary metals plus the secondary metals, was based on 1980 costs. These were escalated to 1982 values using assumptions as to the appropriate inflation rate for various cost components. Some costs, such as fuel and power, were recomputed from unit rates that are the same as the four-metal base case. The total three-metal plant investment rose from $1.494 billion to $1.629 billion, a 9 percent increase from 1980 to 1982, while fixed capital investment rose only 6.3 percent because of the recently reduced rates of inflation for capital goods. Operating costs in aggregate rose 13.5 percent. The largest contributor was power costs, which nearly doubled. Revenues were the same, reflecting depressed metals markets.

Table 14 compares the three-metal, reduction/ammoniacal leach process of three million short tons per annum to the four-metal smelting process of half the throughput. However, both are in 1982 dollars, located in southern California and use minimum cogeneration of electricity with coal as the primary energy source.

In addition, the processing of the three-metal tailings to recover manganese was examined. The additional costs for this process option, while significant increases, result in the generation of greatly increased revenues.

In Table 14 costs and returns of a base-case, 1.5 million dry short tons per annum, four-metal smelting process were compared with those of a 3.0 million dry short tons per annum, reduction-ammoniacal leach process, both with and without recovery of manganese from the three-metal process rejects. Both of the four-metal processes show higher

Table 14. Comparison of Three- and Four-Metals Plants

Process	4-Metal BASE CASE	2-Metal CASE	3-Metal Plus Manganese
	Smelting Mn, Hydrometallurgical for Cu-Ni-Co	Reduction/ Ammoniacal Leach	Reduction/ Ammoniacal Leach, plus Smelting
Annual Tonnage of Nodules (million dry short tons)	1.5	3.0	3.0
Total Investment Funding	$1,432.3	$1,573.7	$2,042.7
Fixed Capital Investment	869.3	1,084.7	1,369.7
Net Annual Revenue	524.6	408.8	1,069.9
Annual Operating Costs	335.8	260.4	568.4
S.L. Depreciation Expense	164.2	204.5	258.7
Preparatory Expenditures	195.0	195.0	195.0
Before Taxes			
Average Profit	183.5	144.3	440.8
Return on Total Investment	12.87	9.17	24.03
Return on Fixed Capital	21.11	13.31	35.83
Payback on Total Investment	14-1	17-1	10-5
Payback on Fixed Investment	11-1	13-10	9-1
Internal Rate of Return	8.57	5.23	16.37
After Taxes			
Average Profit	140.3	133.7	326.6
Return on Total Investment	9.84	7.80	15.99
Return on Fixed Capital	16.14	11.31	23.85
Payback on Total Investment	14-4	17-3	10-11
Payback on Fixed Capital	11-1	13-10	9-2
Internal Rate of Return	6.41	3.99	12.35

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

returns than the three-metal base-case process; the return for the larger, three million ton per year manganese recovery from three-metal process rejects is significantly greater than for the smaller smelting process. This increase in return is in part attributable to the economics of scale inherent in a larger operation with reduced capital and operating costs per unit of throughput. This analysis cannot show this ranking would remain unchanged if the alternatives were compared at the same processing throughput rate. Clearly, however, the manganese recovery options are more attractive. Total funding requirements increase by $315 million and total operating costs increase about $365 million per year. However, revenues increase by $675 million per year, so that average profits increase by $357.7 million per year and $202.3 million per year before and after taxes, respectively. These represent pre- and after-tax marginal rates of return of 98 and 55 percent, respectively, on funding, both of which are compelling arguments for recovering manganese.

These results suggest the likely configuration of a nodules mining and processing venture: manganese will be recovered at the process plant, although perhaps not to the maximum extent possible. Also, a pioneer venture will be designed to operate at the maximum rate consistent with capital availability and market penetration limits.

Pacific Northwest Plant Location

One alternative to avoid the high electric power costs of southern California of 11 cents per kilowatt-hour is to locate the four-metal smelting plant in the Pacific Northwest. Electricity at the low price of 3 cents per kilowatt-hour makes generation of any electricity on-site (whether by coal, oil or gas) more expensive than purchase. Therefore minimum cogeneration (with process steam) is assumed from coal as fuel. Lower hydroelectric power costs, and possible cost savings in land, pollution control, construction permitting and other elements, make this prospect intriguing, although cost savings were not estimated. The certain extra costs for longer transportation from the deep ocean mining sites were computed, and are shown in Table 8. A pair of larger transport ships, about 75,000 DWT each, would be needed to maintain the mining rate. Therefore, a larger unloading berth is needed. The mining and processing sectors are unchanged in this alternative evaluation, a conservative assumption.

The result of this alternate case computation is shown in Table 15. Even with the known higher costs and no savings except for $140 million in electric power costs, a definite improvement in returns is produced, a greater improvement than any other alternative produces.

Foreign Transport Ship Chartering

Use of low-cost foreign vessels and foreign crews would also reduce the transport sector costs by a large fraction. Under Public Law 96-283 only one U.S.-registered ship need be utilized by each venture. The foreign ships would be the same size as described in the base case and could presumably be permitted under the "reciprocal states" language of the Deep Seabed Hard Minerals Resources Act. The mining ships costs are also foreign built and manned in this alternative. Because no new Merchant Marine subsidies, capital or operating, have been included in the Reagan Administration's budgets, U.S. vessel costs

Table 15. Comparison of Four Metal Base Case in Southern California With the Pacific Northwest

	4-Metal BASE CASE	Pacific Northwest
Total Investment Funding	$1,432.3	$1,446.8
Fixed Capital Investment	869.3	883.8
Net Annual Revenue	524.6	524.6
Annual Operating Costs	335.8	244.6
S.L. Depreciation Expense	164.2	167.0
Preparatory Expenditures	195.0	195.0
<u>Before Taxes</u>		
Average Profit	183.5	284.5
Return on Total Investment	12.87	19.66
Return on Fixed Capital	21.11	32.19
Payback on Total Investment	14-1	11-9
Payback on Fixed Investment	11-1	9-6
Internal Rate of Return	8.57	13.21
<u>After Taxes</u>		
Average Profit	140.3	185.8
Return on Total Investment	9.84	12.84
Return on Fixed Capital	16.14	21.02
Payback on Total Investment	14-4	11-9
Payback on Fixed Capital	11-1	9-6
Internal Rate of Return	6.41	9.79

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

probably could not be equated to foreign vessel costs via the subsidy route. The operating cost of long-term chartering of foreign-built and manned vessels could be about the same as for U.S. vessels, but no investment would be needed.

Table 16 summarizes the possible savings. An increase of about 0.5 percent in after-tax IROR results from about a $3.6 million increase in average profit, a nominal but worthwhile gain.

Shallow Ports

If U.S. ports are not sufficiently deepened to at least 45 ft at low water, additional costs will be incurred to transport nodules into shallower depth ocean ports. These additional costs for the operator could arise in several forms.

If more, but smaller, ships are used for ocean transport, the unit transportation costs will increase, principally because of the dis-economies of small scale from adding an extra ship to the fleet with another crew.

Another alternative would be to use the desired size nodule trans-ports, and transfer nodules and fuel to and from barges at a deepwater location outside the American port terminals.

Table 9 indicates that the double handling needed between large nodule transport ships and smaller barges more than doubles the terminal and handling costs, and essentially adds direct costs of almost two to over three dollars per ton of wet nodules handled. Clearly $80 million could be better spent over the project life on port channel dredging for the benefit of all ocean shipping, rather than this amount for nodules alone.

Table 16. Comparison of Four Metal Base Case and American Ships With Foreign Ship Charters

	4-Metal BASE CASE	Foreign Ship Charters
Total Investment Funding	$1,432.3	$1,398.3
Fixed Capital Investment	869.3	835.3
Net Annual Revenue	524.6	524.5
Annual Operating Costs	335.8	327.6
S.L. Depreciation Expense	164.2	157.8
Preparatory Expenditures	195.0	195.0
Before Taxes		
Average Profit	183.5	191.7
Return on Total Investment	12.87	13.71
Return on Fixed Capital	21.11	22.95
Payback on Total Investment	14-1	13-7
Payback on Fixed Investment	11-1	10-9
Internal Rate of Return	8.57	9.25
After Taxes		
Average Profit	140.3	144.2
Return on Total Investment	9.84	10.31
Return on Fixed Capital	16.14	17.26
Payback on Total Investment	14-4	13-10
Payback on Fixed Capital	11-1	10-9
Internal Rate of Return	6.41	6.91

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

Table 17 indicates that the double handling (a transshipment mode) of operation into shallow ports causes a decrease of IROR to 8.1 percent before, and 6.0 percent after, tax.

Shorter Construction Period

A shorter construction period could be achieved with fast-track construction methods, expedited approval of permits and prompt ordering of custom machinery for the process plant, terminals and ships. This acceleration is considered unlikely for the southern California plant site. Rather than six years as in the base case, a much-accelerated construction schedule of four years, including six months of debugging and trial operations as in the base case, has been evaluated to review the impact on the project returns. The construction costs spread in the base case over Years 1 and 2 (including land) were all added into the cost of Year 3; in Years 4 and 5 costs remained the same. But no costs are shown for Years 1 and 2 under this alternate computation by the Payout Model.

The delayed-start sensitivity studies are reported next, and these two analyses together represent a range of 4 to 10 years of construction period, as illustrated in Figure 5 and shown in Table 18.

Sensitivity Tests

In addition to the alternatives described above, sensitivity was tested to measure the change of returns with variations in the assumed base-case values. These changes reflect the real range of variations in costs typical of well-specified, standard industrial projects, plus the greater range of cost variability due to the uncertainties and

Table 17. Comparison of Four Metal Base Case and 45' Deep Ports with Shallow Ports

	4-Metal BASE CASE	Shallow Ports
Total Investment Funding	$1,432.3	1,467.3
Fixed Capital Investment	869.3	909.3
Net Annual Revenue	524.6	524.6
Annual Operating Costs	335.8	339.4
S.L. Depreciation Expense	164.2	171.8
Preparatory Expenditures	195.0	195.0
<u>Before Taxes</u>		
Average Profit	183.5	179.9
Return on Total Investment	12.87	12.26
Return on Fixed Capital	21.11	19.79
Payback on Total Investment	14.1	14.5
Payback on Fixed Investment	11.1	11.5
Internal Rate of Return	8.57	8.06
<u>After Taxes</u>		
Average Profit	140.3	139.5
Return on Total Investment	9.84	9.51
Return on Fixed Capital	16.14	15.34
Payback on Total Investment	14-4	14-9
Payback on Fixed Capital	11-1	11-5
Internal Rate of Return	6.41	6.03

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

design risks of a new system being built and operated by a pioneer venture in deep ocean mining. Further, regulatory uncertainities cause cost variations due to delays and late changes in design, with no offsetting benefits to the pioneer venture.

Therefore, the computer Payout Model was exercised heavily to measure the changes due to variations in:

(a) construction period before start of production;

(b) total capital cost variations;

(c) process sector capital or operating costs, and both;

(d) process sector power and labor costs;

(e) electrical power costs with different levels of plant-size cogeneration of steam and electricity with coal or fuel oil;

(f) mining sector total costs;

(g) transport sector total costs;

(h) preparatory period expenditures;

(i) nickel or manganese metal prices, and all metal prices changes together;

(j) debt interest rates; and

(k) varied overall profits tax rates.

Delay in Start of Operations

In the base case, the plant owner assumed that permission to operate will be received after construction is complete. Reasons for possible delay to the start of the completed plant could be strikes, manufacturing delays or process failures to perform as designed requiring re-work, and difficulties in receiving all the necessary permits. For all of these reasons, the impact of these delays on the payout was measured, as shown in Table 18. Combining these dalys with the base case, and with the previously described alternative of a shorter construction period, results in the approximate graph in Figure 5 prepared from the data in Table 18. For the delayed start-up cases, the pre-operation period costs are assumed to be $200 million dollars annually, but no extra cost or saving is applied to the accelerated construction case. As indicated, the delays have a material adverse impact, but acceleration of the construction schedule does not reveal much benefit. (If construction period debts were included, more benefit from acceleration would be expected.)

Preparatory Period Expenditures

The base-case estimate of the 1982 dollar value of preparatory period expenditures, which partners in the venture would pay to participate in the program is $195 million from escalation of the 1980 report figure. This in turn was a consensus figure from the amounts actually expended and budgeted by the various consortia.

The selected value may be incorrect, or participants may be able to join the venture without buying in. Therefore, a range of preparatory period expenses were examined, from zero to $500 million. The results for the four values assumed in the range to estimate sensitivity are shown in Table 19. The sensitivity of the after-tax internal rate of return to the amount of this front-end expense is shown in Figure 6. In all cases the expense is taken as a cash outflow in Year 1, and immediately expensed because 15-year tax carry-forward is available.

The impact of large changes in expenditures during the preparatory period is not as great as expected, because these changes in base-case,

Table 18. Comparison of Four Metal Base Case With Delayed or Accelerated Construction Period

	START UP PERIOD			
	Acceleration 4 Years	4-Metal BASE CASE 6 Years	DELAY 8 Years	DELAY 10 Years
Total Investment Funding	$1,432.3	$1,432.3	$1,432.3	$1,432.3
Fixed Capital Investment	869.3	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	335.8	335.8
S.L. Depreciation Expense	164.2	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0	195.0
Before Taxes				
Average Profit	183.5	183.5	148.7	119.6
Return on Total Investment	12.81	12.87	10.38	8.35
Return on Fixed Capital	21.11	21.11	17.10	13.76
Payback on Total Investment	12-1	14-1	18-3	22-4
Payback on Fixed Investment	9-1	11-1	15-3	19-4
Internal Rate of Return	8.92	8.57	5.41	3.45
After Taxes				
Average Profit	140.6	140.3	118.0	99.2
Return on Total Investment	9.82	9.84	8.24	6.93
Return on Fixed Capital	16.18	16.14	13.58	11.41
Payback on Total Investment	12-4	14-4	18-6	22-8
Payback on Fixed Capital	9-1	11-1	15-3	19-4
Internal Rate of Return	6.66	6.41	3.99	2.54

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

Table 19. Comparison of Base Case With Preparatory Period Expenditure Variations

	PREPARATORY PERIOD EXPENDITURE (Millions Dollars, 1982)				
	0	100	4-Metal BASE CASE 195	350	500
Total Investment Funding	$1,237.3	$1,337.3	$1,432.3	$1,587.3	$1,737.3
Fixed Capital Investment	869.3	869.3	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	335.8	335.8	335.8
S.L. Depreciation Expense	164.2	164.2	164.2	164.2	164.2
Preparatory Expenditures	0	100.0	195.0	350.0	500.0
Before Taxes					
Average Profit	193.3	193.3	183.5	193.3	193.3
Return on Total Investment	15.62	14.45	12.87	12.18	11.12
Return on Fixed Capital	22.23	22.23	21.11	22.23	22.23
Payback on Total Investment	13-1	13-7	14-1	14-11	15-9
Payback on Fixed Investment	11-1	11-1	11-1	11-1	11-1
Internal Rate of Return	10.94	9.72	8.57	7.49	6.49
After Taxes					
Average Profit	131.7	134.0	140.3	139.7	143.2
Return on Total Investment	10.64	10.02	9.84	8.80	8.24
Return on Fixed Capital	15.15	15.41	16.14	16.07	16.47
Payback on Total Investment	13-4	13-10	14-4	15-10	15-11
Payback on Fixed Capital	11-1	11-1	11-1	11-1	11-1
Internal Rate of Return	7.90	6.95	6.41	5.21	4.44

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

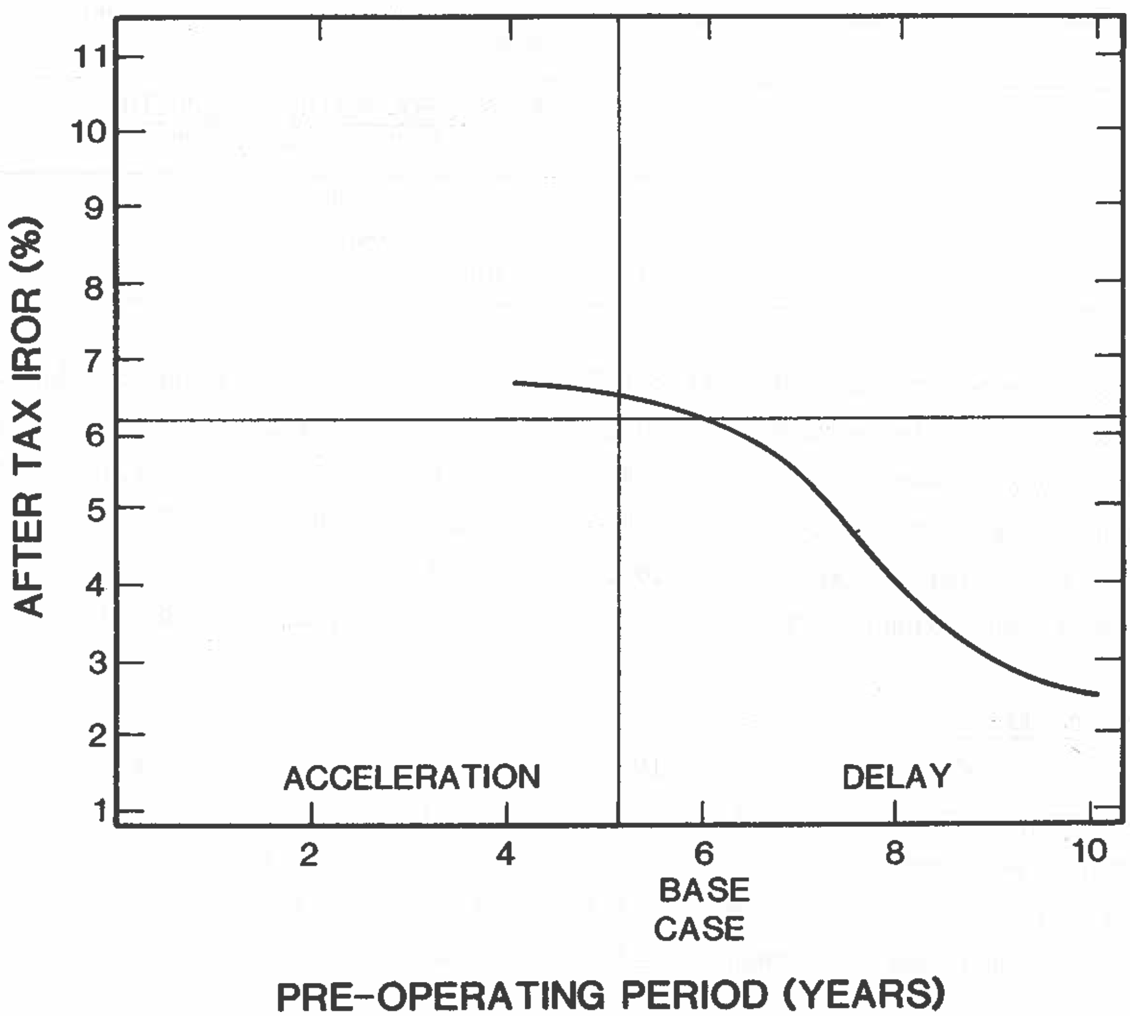


Figure 5. Sensitivity of Return to Construction Period Before Start

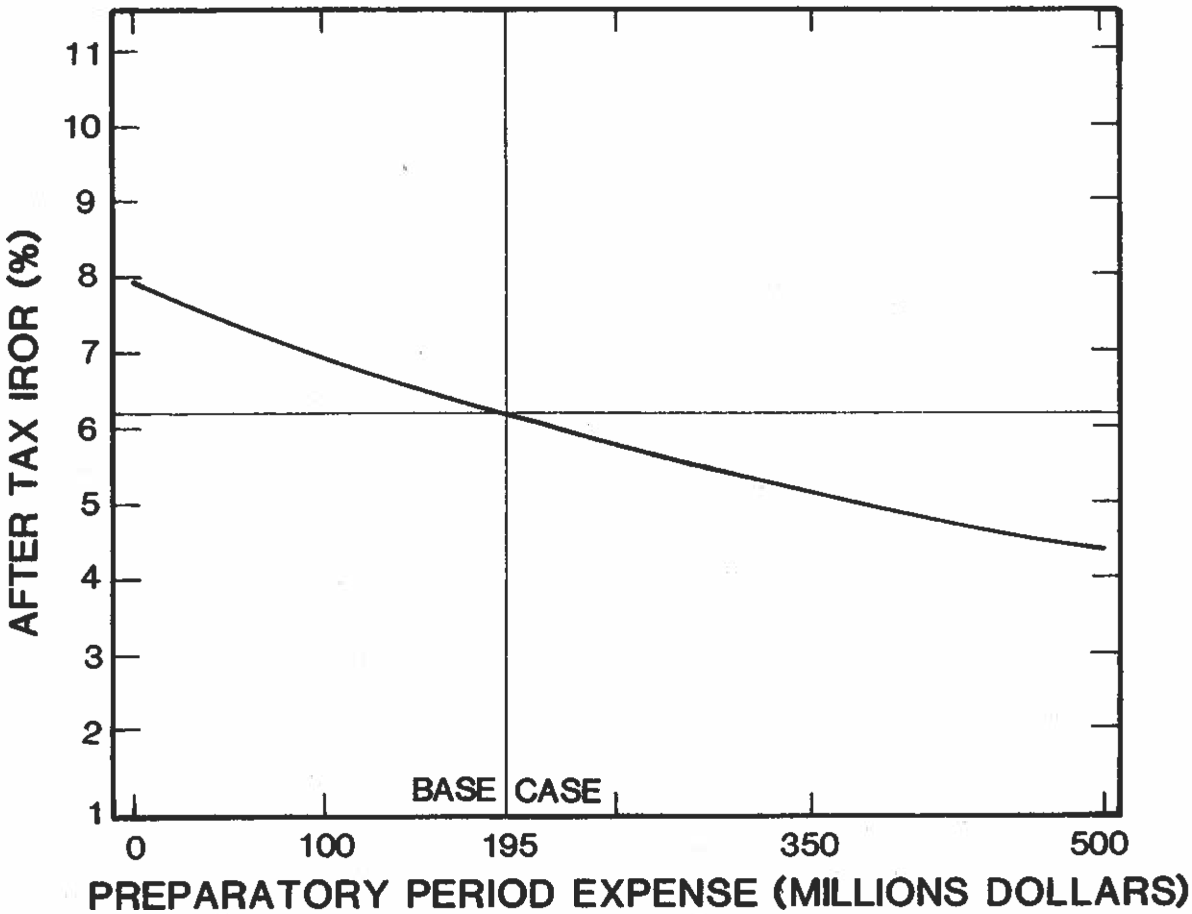


Figure 6. Sensitivity of Return to Preparatory Period Expenses

front-end costs taken in Year 1 are -13.6 percent of total investment for zero expenditure, to 21.3 percent for the maximum expenditure calculated. The total elimination of all R&D and Prospecting and Exploration costs, adds almost 1.5 percent ot the after-tax IROR, as computed here.

Capital Costs

The sensitivity of the returns to variations in total capital costs in all sectors is measured by arbitrarily assuming a wide range of capital costs, through low costs from competitive bidding in a depressed economy, or increased costs due to insufficient data now being available during the present R&D phase of the ocean mining development. Although the ranges computed assumed ±30 percent variation in capital cost, Table 20, the project team feels that realistic ranges are +25 percent, but only -10 percent, which is signified by the dashed line in Figure 7. Clearly, even the most optimistic capital cost expectations alone cannot substantially improve the pioneer venture's attractiveness.

Mining Sector Costs

The high-technology and risk sectors are related to the ocean mining equipment and to the processing plant. This first test of sensitivity for the ocean mining system alone examined a range of costs ±30 percent (an arbitrary value based on examination of other vessel project data) for both the total capital and operating costs of the Sector 2 (mining) only. The need for reliability may well raise costs, but a technical breakthrough in a few areas could result in major cost reductions. The results are shown in Table 21 and Figure 8.

Table 20. Comparison of Four Metal Base Case With Total Capital Cost Variations

	TOTAL CAPITAL COSTS -30%	4-Metal BASE CASE	+30%
Total Investment Funding	$1,170.9	$1,432.3	$1,693.7
Fixed Capital Investment	607.9	869.3	1,130.7
Net Annual Revenue	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	335.8
S.L. Depreciation Expense	114.8	164.2	213.6
Preparatory Expenditures	195.0	195.0	195.0
<u>Before Taxes</u>			
Average Profit	193.2	183.5	193.3
Return on Total Investment	16.50	12.87	11.42
Return on Fixed Capital	31.78	21.11	17.10
Payback on Total Investment	12-9	14-1	15-6
Payback on Fixed Investment	9-9	11-1	12-6
Internal Rate of Return	10.83	8.57	7.11
<u>After Taxes</u>			
Average Profit	129.1	140.3	143.2
Return on Total Investment	11.03	9.84	8.45
Return on Fixed Capital	21.24	16.14	12.66
Payback on Total Investment	13-2	14-4	15-8
Payback on Fixed Capital	9-9	11-1	12-6
Internal Rate of Return	7.77	6.41	4.97

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

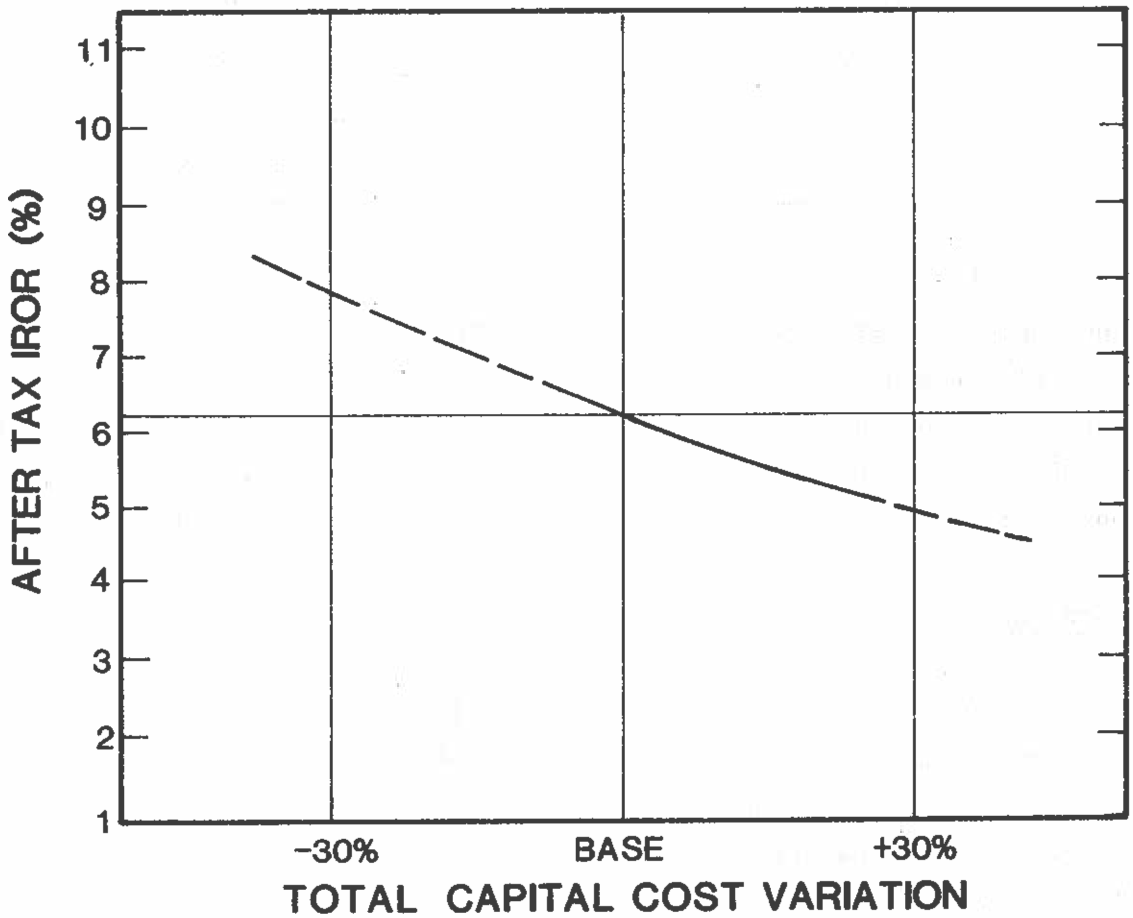


Figure 7. Sensitivity of Return to Total Capital Costs

Table 21. Comparison of Four Metal Base Case With Total Mining Sector Cost Variations

	MINING SECTOR TOTAL COSTS		
	+30%	4-Metal BASE CASE	-30%
Total Investment Funding	$1,486.3	$1,432.3	$1,378.3
Fixed Capital Investment	923.3	869.3	815.3
Net Annual Revenue	529.6	524.6	524.6
Annual Operating Costs	347.5	335.8	324.1
S.L. Depreciation Expense	174.5	164.2	154.0
Preparatory Expenditures	195.0	195.0	195.0
Before Taxes			
Average Profit	181.6	183.5	205.0
Return on Total Investment	12.22	12.87	14.87
Return on Fixed Capital	19.67	21.11	25.14
Payback on Total Investment	14-11	14-1	13-4
Payback on Fixed Investment	11-9	11-1	10-7
Internal Rate of Return	7.74	8.57	9.79
After Taxes			
Average Profit	131.3	140.3	141.0
Return on Total Investment	8.83	9.84	10.23
Return on Fixed Capital	14.22	16.14	17.30
Payback on Total Investment	15-2	14-4	13-8
Payback on Fixed Capital	11-9	11-1	10-7
Internal Rate of Return	5.41	6.41	7.01

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

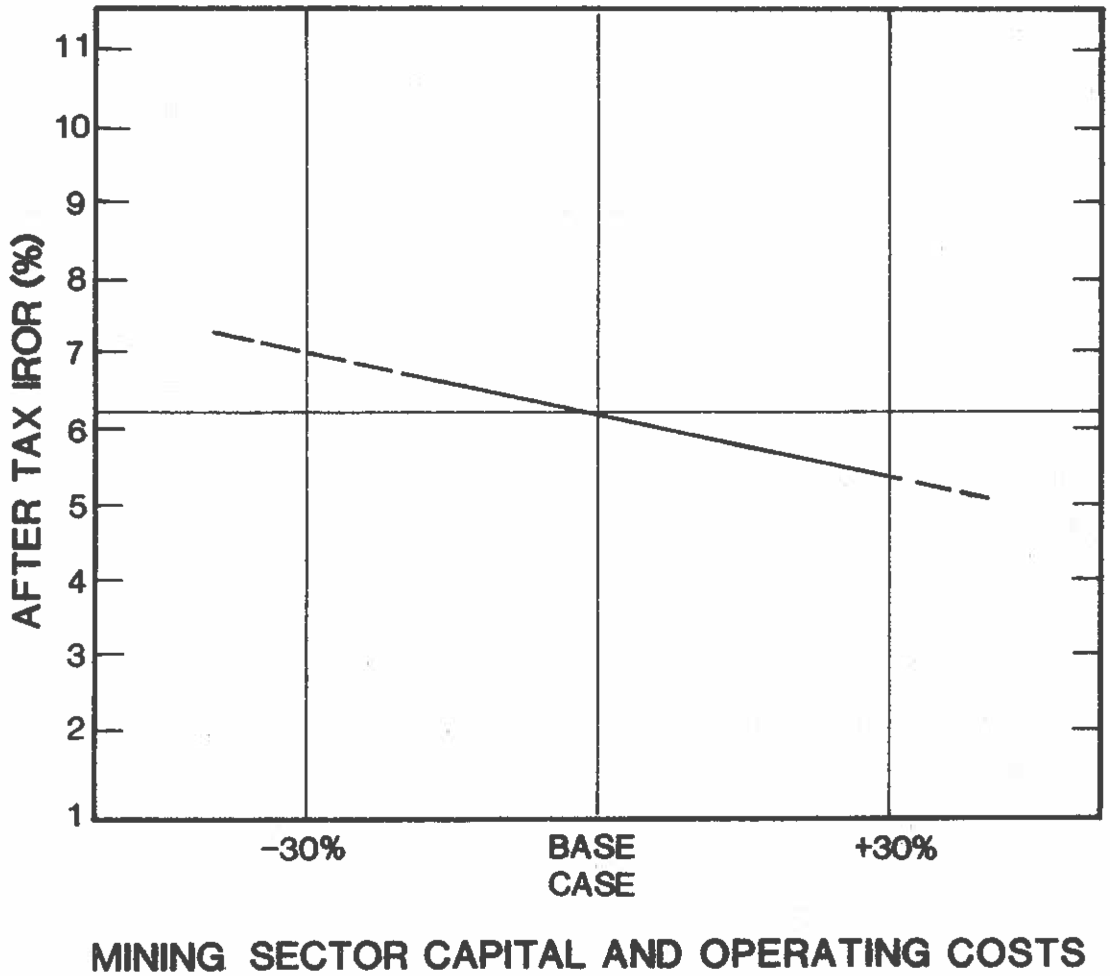


Figure 8. Sensitivity of Return to Mining Sector Costs

Transport Sectors Costs

Similar to those in the mining sector sensitivity analysis above, the various costs associated with sea and land transport were arbitrarily varied by ±30 percent for all costs, to measure the change in payout. The totals of capital and operating costs in Sectors 3, 4 and 5 only were varied, keeping the same investment timing as the base case. Because these areas are relatively well-defined, as compared to deep ocean mining equipment and vessels and the nodule processing plant, this range seems relatively large when no technical breakthrough of magnitude can be expected. The results are shown in Table 22 and Figure 9 by a dashed line beyond the 10 percent range, which is more reasonable, as discussed in the section on cost variability at the end of Section II.

Process Sector Costs

Sector 6 (Processing) constitutes the largest fixed investment and operating costs protions, 58 and 75 percent, respectively, of the totals. Therefore, more detailed analyses are appropriate and are performed of the Process sector sensitivity by component, as compared to the overall sensitivity for total areas as just described. For comparison, first the capital costs, then the operating costs, and then both capital and operating costs together for the process sector were varied by the same range used above, ±30 percent. Because of the relative risks of the process sector, this higher range seems more appropriate here.

Table 22. Comparison of Four Metal Base Case With Transport Sector Total Cost Variations

	TRANSPORT SECTOR TOTAL COSTS		
	+30%	4-Metal BASE CASE	-30%
Total Investment Funding	$1,485.2	$1,432.3	$1,379.4
Fixed Capital Investment	922.2	869.3	816.4
Net Annual Revenue	524.6	524.6	524.6
Annual Operating Costs	334.2	335.8	327.5
S.L. Depreciation Expense	174.1	164.2	154.4
Preparatory Expenditures	195.0	195.0	195.0
Before Taxes			
Average Profit	184.9	183.5	201.5
Return on Total Investment	12.45	12.87	14.61
Return on Fixed Capital	20.05	21.11	24.68
Payback on Total Investment	14-9	14-1	13-6
Payback on Fixed Investment	11-8	11-1	10-8
Internal Rate of Return	7.93	8.57	9.60
After Taxes			
Average Profit	133.0	140.3	139.2
Return on Total Investment	8.96	9.84	10.09
Return on Fixed Capital	14.43	16.14	17.05
Payback on Total Investment	15-0	14-4	13-9
Payback on Fixed Capital	11-8	11-1	10-8
Internal Rate of Return	5.56	6.41	6.86

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

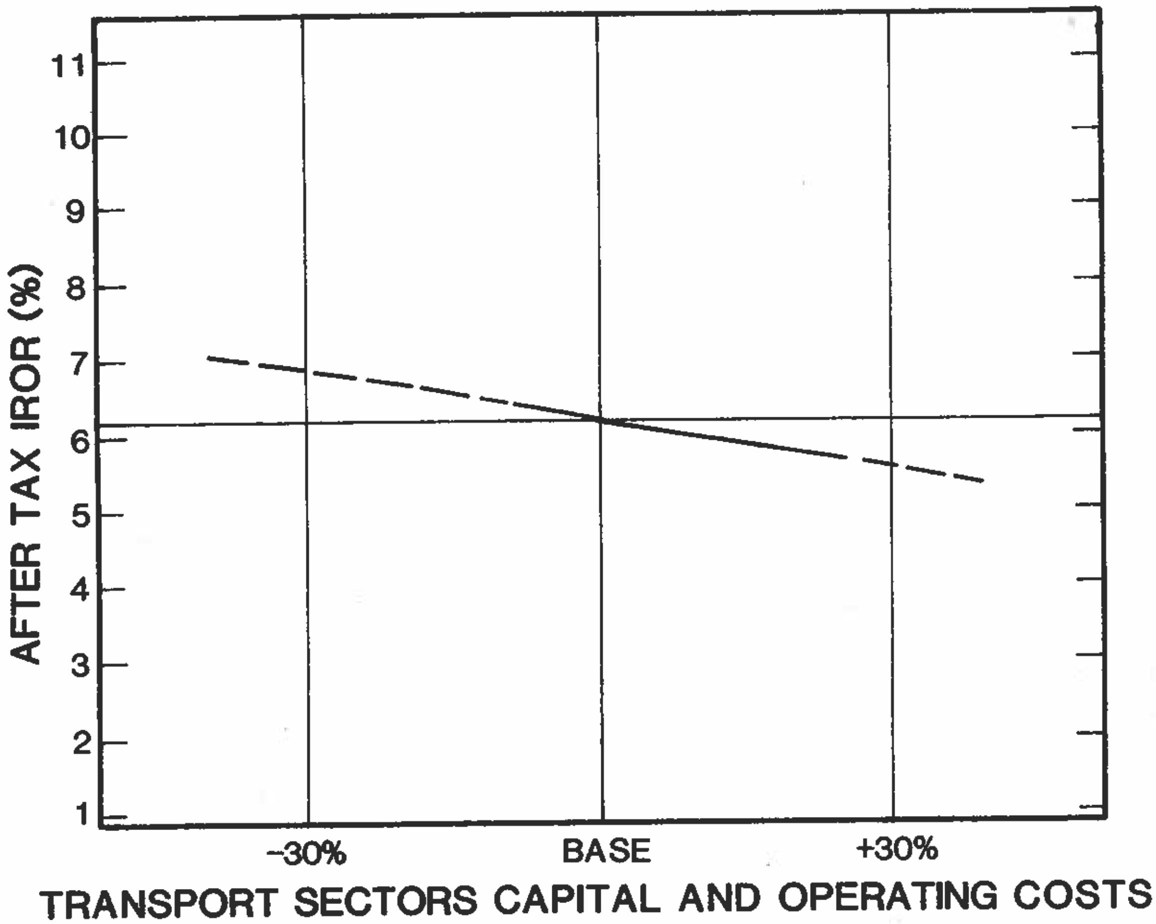


Figure 9. Sensitivity of Return to Transport Sector Costs

Without major changes in the process technology used, capital costs are unlikely to be reduced by 30 percent from the base-case estimate. Operating costs are much more site-specific and therefore more variable. The results are shown in Table 23 and Figure 10.

As these results indicate, a 30 percent change in operating costs alters the after-tax return on investment by about 35 percent, almost twice the impact as the same percentage change in capital costs. This impact is also considerably larger than the impact of all of the transport sectors, or of the mining sector, or the total capital investment under changes of the same ±30 percent magnitude. Therefore, the process sector operating costs were analyzed in more detail, first to examine labor costs, and finally power costs, including cogeneration alternatives.

Table 25 illustrates the sensitivity results for the ±30 percent changes in labor, Table 24 for ±50 percent change in power operating costs for the process sector. Figure 11 shows the relatively larger importance of the 11 cents per kilowatt-hour electrical power costs, considered further under the next heading, and reported earlier as important in the Pacific Northwest alternative.

Table 26 summarizes the evaluation of costs of purchased power and use of either coal or fuel oil as the primary energy source. These results are also presented in Figure 12 for the minimum steam cogeneration, and the maximum complete process plant power cogeneration on site.

Table 23. Comparison of Four Metal Base Case With Process Sector 6 Cost Variations

	PROCESS SECTOR 6 SENSITIVITY*					
	Capital Costs Only		Operating Costs Only		Capital & Operating	
	+30%	-30%	+30%	-30%	+30%	-30%
Total Investment Funding	1,584.3	1,280.3	1,432.3	1,432.3	1,584.3	1,280.3
Fixed Capital Investment	1,021.3	717.3	869.3	869.3	1,021.3	717.3
Net Annual Revenue	524.6	524.6	524.6	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	411.8	259.8	411.8	259.8
S.L. Depreciation Expense	193.1	135.4	164.2	164.2	193.1	135.4
Preparatory Expenditures	195.0	195.0	195.0	195.0	195.0	195.0
Before Taxes						
Average Profit	193.3	193.3	117.3	269.3	117.3	269.3
Return on Total Investment	12.20	15.09	8.19	18.80	7.40	21.03
Return on Fixed Capital	18.93	26.94	13.49	30.98	11.48	37.54
Payback on Total Investment	14-11	13-4	19-7	11-9	20-11	11-2
Payback on Fixed Investment	11-11	10-4	14-7	9-8	15-11	9-1
Internal Rate of Return	7.74	9.93	3.87	12.63	3.03	13.97
After Taxes						
Average Profit	140.2	132.1	95.1	177.2	99.2	173.1
Return on Total Investment	8.85	10.32	6.64	12.37	6.26	13.52
Return on Fixed Capital	13.73	18.41	10.94	20.38	9.71	24.13
Payback on Total Investment	15-0	13-8	20-0	11-11	21-2	11-5
Payback on Fixed Capital	11-11	10-4	14-7	9-8	15-11	9-1
Internal Rate of Return	5.44	7.08	2.42	9.32	1.87	10.35

*Percent change from Base Case cost to produce tabulated values.

Note: Dollar amounts in millions of 1982 dollars.
Returns as annual percentage.
Payback periods in years and months.

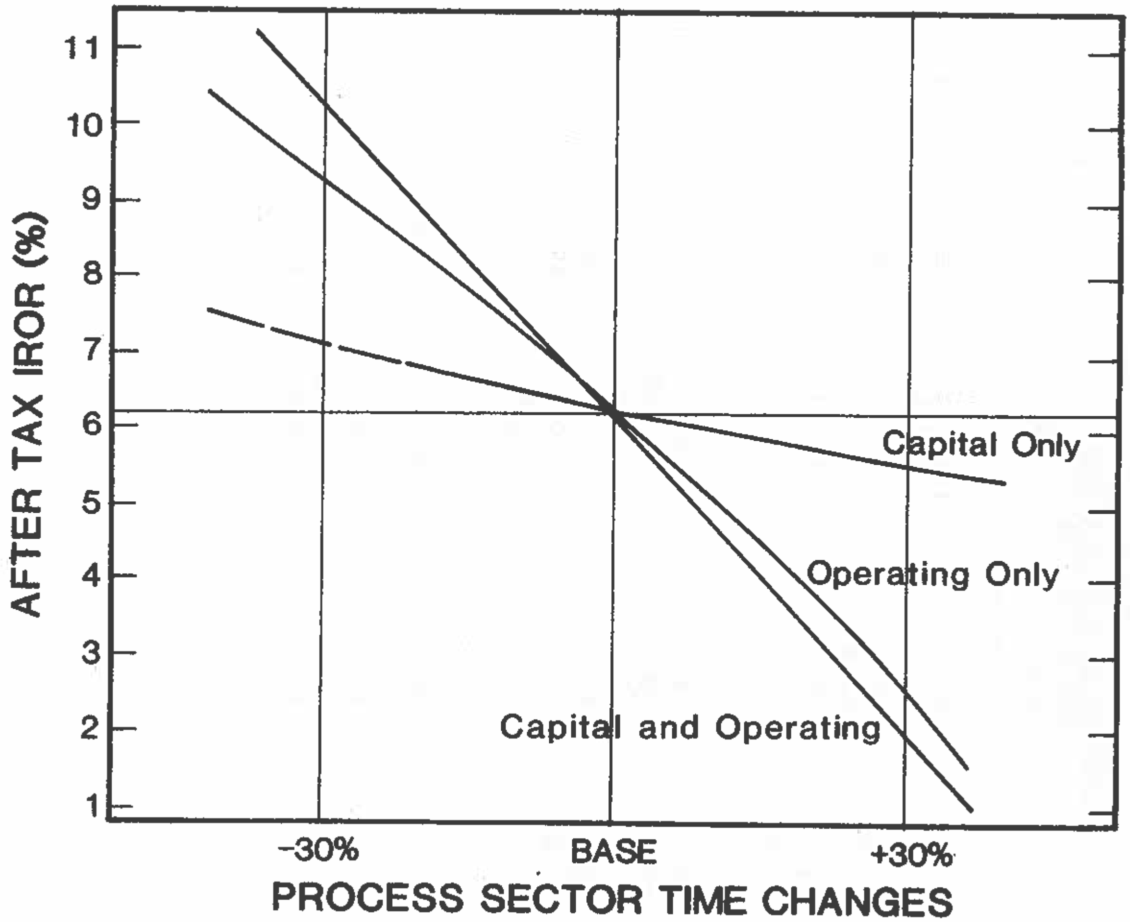


Figure 10. Sensitivity of Return to Process Sector Costs

Table 24. Comparison of Four Metal Base Case With Sector 6 - Process Power Cost Variations

	PROCESS POWER COST SENSITIVITY		
	+50%	4-Metal BASE CASE*	-50%
Total Investment Funding	$1,432.3	$1,432.3	$1,432.3
Fixed Capital Investment	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6
Annual Operating Costs	371.8	335.8	259.8
S.L. Depreciation Expense	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0
<u>Before Taxes</u>			
Average Profit	157.3	183.5	269.3
Return on Total Investment	10.98	12.87	18.80
Return on Fixed Capital	18.09	21.11	30.98
Payback on Total Investment	16-0	14-1	11-9
Payback on Fixed Investment	12-4	11-1	9-8
Internal Rate of Return	6.61	8.57	12.63
<u>After Taxes</u>			
Average Profit	116.7	140.3	117.2
Return on Total Investment	8.15	9.84	12.37
Return on Fixed Capital	13.43	16.14	20.38
Payback on Total Investment	16-4	14-4	11-11
Payback on Fixed Capital	12-4	11-1	9-8
Internal Rate of Return	4.51	6.41	9.32

*11¢ per kilowatt hour

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

Table 25. Comparison of Four Metal Base Case With Sector 6 - Process Labor Cost Variations

	PROCESS LABOR COST SENSITIVITY		
	+30%	4-Metal BASE CASE*	-30%
Total Investment Funding	$1,432.3	$1,432.3	$1,432.3
Fixed Capital Investment	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6
Annual Operating Costs	342.8	335.8	328.8
S.L. Depreciation Expense	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0
Before Taxes			
Average Profit	186.3	183.5	200.3
Return on Total Investment	13.01	12.87	13.98
Return on Fixed Capital	21.43	21.11	23.04
Payback on Total Investment	14-5	14-1	13-10
Payback on Fixed Investment	11-4	11-1	10-11
Internal Rate of Return	8.36	8.57	9.15
After Taxes			
Average Profit	132.4	140.3	139.9
Return on Total Investment	9.24	9.84	9.77
Return on Fixed Capital	15.23	16.14	16.10
Payback on Total Investment	14.9	14-4	14-0
Payback on Fixed Capital	11-4	11-1	10-11
Internal Rate of Return	5.88	6.41	6.51

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

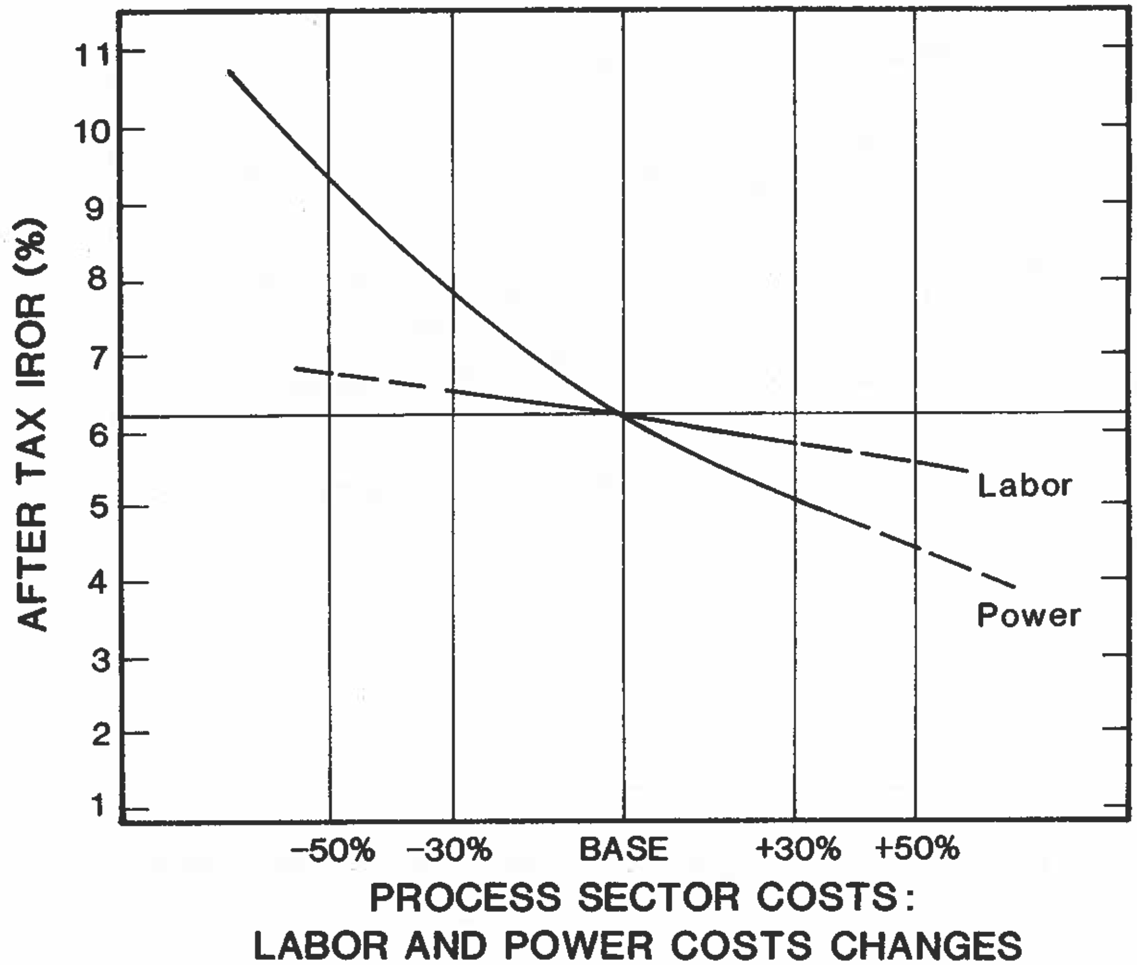


Figure 11. Sensitivity of Return to Process Power and Process Labor Costs

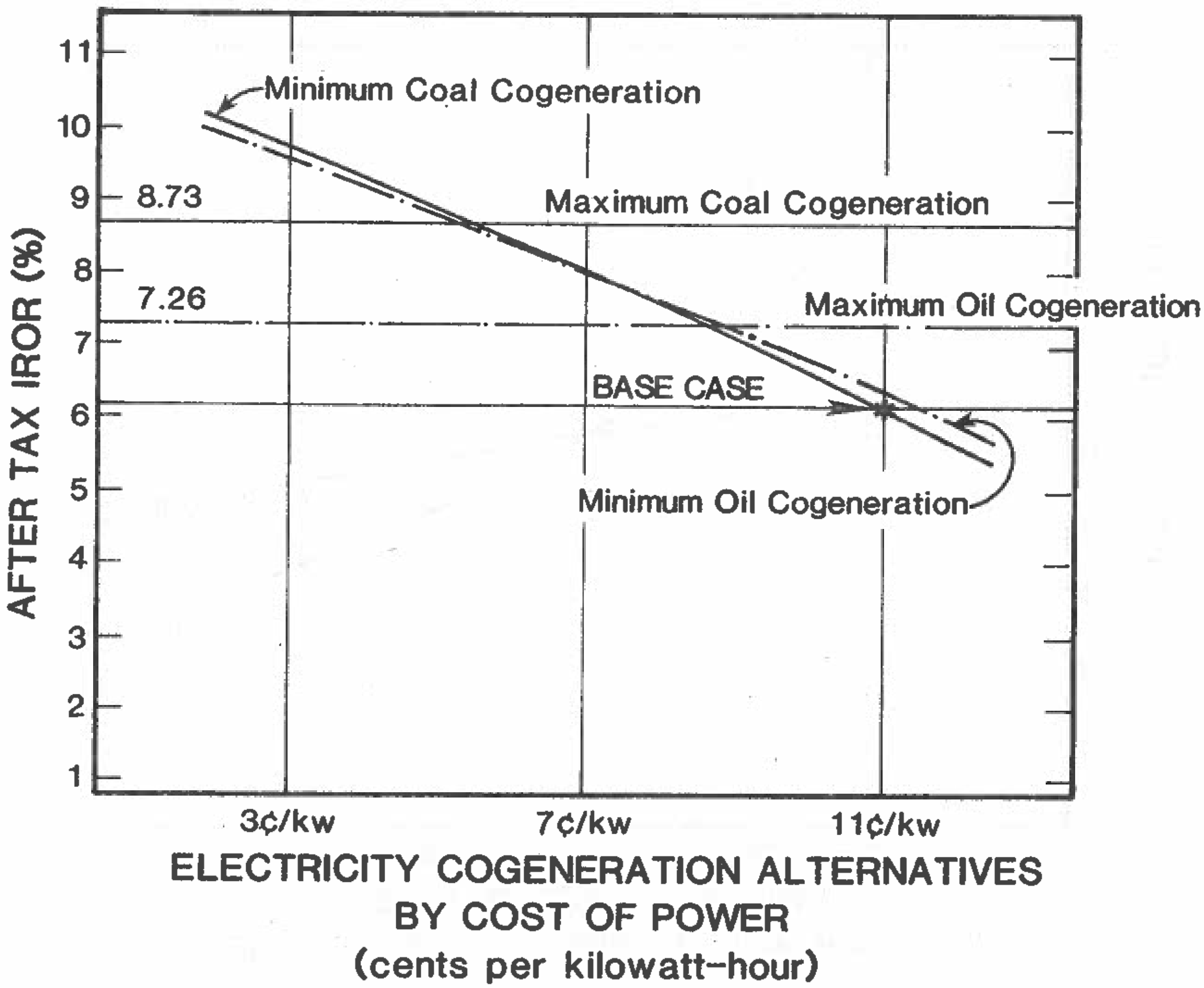


Figure 12. Sensitivity of Return to Electrical Power Cogeneration Alternatives

The graph is interpreted to show that the highest internal rate of return is achieved with minimum coal cogeneration if purchased electricity costs less than about five cents per kilowatt-hour. For higher electricity costs, maximum coal cogeneration is most appropriate. If coal cannot be used, fuel oil is only slightly less desirable at lower cost electricity, but at costs greater than about seven cents per kilowatt hour fuel oil is slightly more attractive for minimum co-generation. With power costs greater than 9 cents per kilowatt-hour, maximum cogeneration with oil would be preferred if coal cannot be used.

The Pacific Northwest alternate assumed three cents per kilowatt-hour electricity and minimum coal cogeneration, a feasible combination there, and produces the best payout.

Debt Interest Rates

The Payout Model was used to compute the returns on equity investment when input levels of fixed capital investment were financed by debt obligations. For the base case, no debt was allowed. For this sensitivity analysis, the debt level was set at 75 percent of the fixed capital plant only, using level principal repayment with declining interest amounts over a 15-year period. (Debt percentage, repayment period and method, and interest rate can all be input.) The interest during the construction period, accumulated at the same interest rate, is capitalized at the beginning of operations for repayment. The debt funding is the last provided for the plant construction, after the equity is invested, minimizing interest charges. For purposes of

Table 26. Power Cogeneration Alternatives by Power Cost and Primary Energy Source

	COAL AS FUEL				OIL AS FUEL			
	Maximum No Purchase	Minimum Cogeneration 3¢/kw-hr	7¢/kw-hr	11¢/kw-hr*	Minimum Cogeneration 3¢/kw-hr	7¢/kw-hr	11¢/kw-hr	Maximum No Purchase
Total Investment Funding	1,542.3	1,432.3	1,432.3	1,432.3	1,393.3	1,393.3	1,393.3	1,475.3
Fixed Capital Investment	979.3	869.3	869.3	869.3	830.3	830.3	830.3	912.3
Net Annual Revenue	524.6	524.6	524.6	524.6	524.6	524.6	524.6	524.6
Annual Operating Costs	257.8	249.8	292.8	335.8	260.8	298.8	335.8	305.8
S.L. Depreciation Expense	185.1	164.2	164.2	164.2	156.8	156.8	156.8	172.4
Preparatory Expenditures	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0
Before Taxes								
Average Profit	271.3	279.3	236.3	183.5	268.3	230.3	193.3	223.3
Return on Total Investment	17.59	19.50	16.50	12.87	19.25	16.53	13.87	15.13
Return on Fixed Capital	27.70	32.13	17.18	21.11	32.31	27.73	23.28	24.47
Payback on Total Investment	12-2	11-7	12-7	14-1	11-8	12-7	13-11	13-2
Payback on Fixed Investment	10-0	9-6	10-2	11-1	9-6	10-1	10-11	10-7
Internal Rate of Return	11.86	13.09	11.04	8.57	12.91	11.04	9.04	10.06
After Taxes								
Average Profit	181.2	182.6	159.4	140.3	175.6	155.1	135.1	153.5
Return on Total Investment	11.75	12.75	11.13	9.84	12.60	11.13	9.70	10.41
Return on Fixed Capital	18.75	21.00	18.33	16.14	21.15	18.68	16.27	16.83
Payback on Total Investment	12-4	11-9	12-10	14-4	11-10	12-10	14-2	13-5
Payback on Fixed Capital	10-0	9-6	10-2	11-1	9-6	10-1	10-11	10-7
Internal Rate of Return	8.73	9.69	8.03	6.41	9.53	8.02	6.42	7.26

*Base Case

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

sensitivity analysis, the annual interest rates ranged from zero to 20 percent, and the results are shown in Table 27 and Figure 13. Rates of return are now calculated on the equity portion only, (not on total investment which is unchanged from the base case, no matter what interest rate is charged for the 75 percent debt).

Metal Prices

Parallel to the analyses reported in [17] for the three-metal plant, variations in revenue due to ±30 percent changes in metal sales prices were analyzed. Recently the metals' market prices have been at least 40 percent less than the base case prices for these products. These base prices were developed from long-term trends and are $3.75 per pound for nickel, $5.50 per pound for cobalt, $1.25 for copper and 40 cents for manganese. Prior sensitivity computations [17] were made at the same ±30 percent of price level variations for all four metals, for manganese alone and for nickel alone. (Cobalt and copper prices are much less significant in payout than nickel and manganese, and were not separately evaluated.) Table 28 provides the results computed, and Figure 14 illustrates the variation in after-tax internal rate of return.

Tax Rates

The effective tax rate may be varied by governmental edict, by changes to the profits rate by federal and state officials, and by specification of the depletion method and rate allowable. A high percentage depletion rate will reduce tax payments significantly, or international treaties or agreements could change the tax rate from

Table 27. Sensitivity of Returns to Interest Rate Variations With 75% Debt on Fixed Plant

	INTEREST RATE SENSITIVITY Debt = 75% of Fixed Plant Investment				
	0%	5%	10%	15%	20%
Total Equity	780.3	780.3	780.3	780.3	780.3
Fixed Capital Investment	869.3	869.3	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	335.8	335.8	335.8
S.L. Depreciation Expense	164.2	164.2	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0	195.0	195.0
Before Taxes					
Average Profit	160.7	145.0	127.8	108.9	88.2
Return on Equity	20.59	18.59	16.38	13.95	11.31
Return on Fixed Capital	18.48	16.68	14.70	12.53	10.15
Payback on Equity	12-1	13-7	15-11	18-11	21-9
Payback on Fixed Equity	12-8	14-4	16-8	19-8	22-3
Internal Rate of Return	11.80	10.13	8.29	6.32	4.28
After Taxes					
Average Profit	103.6	94.3	84.1	72.9	60.9
Return on Equity	13.27	12.08	10.77	9.35	7.80
Return on Fixed Capital	11.91	10.84	9.67	8.39	7.00
Payback on Equity	12-1	13-7	15-11	19-7	22-8
Payback on Fixed Capital	12-8	14-4	16-10	21-2	23-7
Internal Rate of Return	8.97	7.45	5.80	4.08	2.39

Note: Dollar amounts in millions of 1982 dollars.
Returns as annual percentage.
Payback periods in years and months.

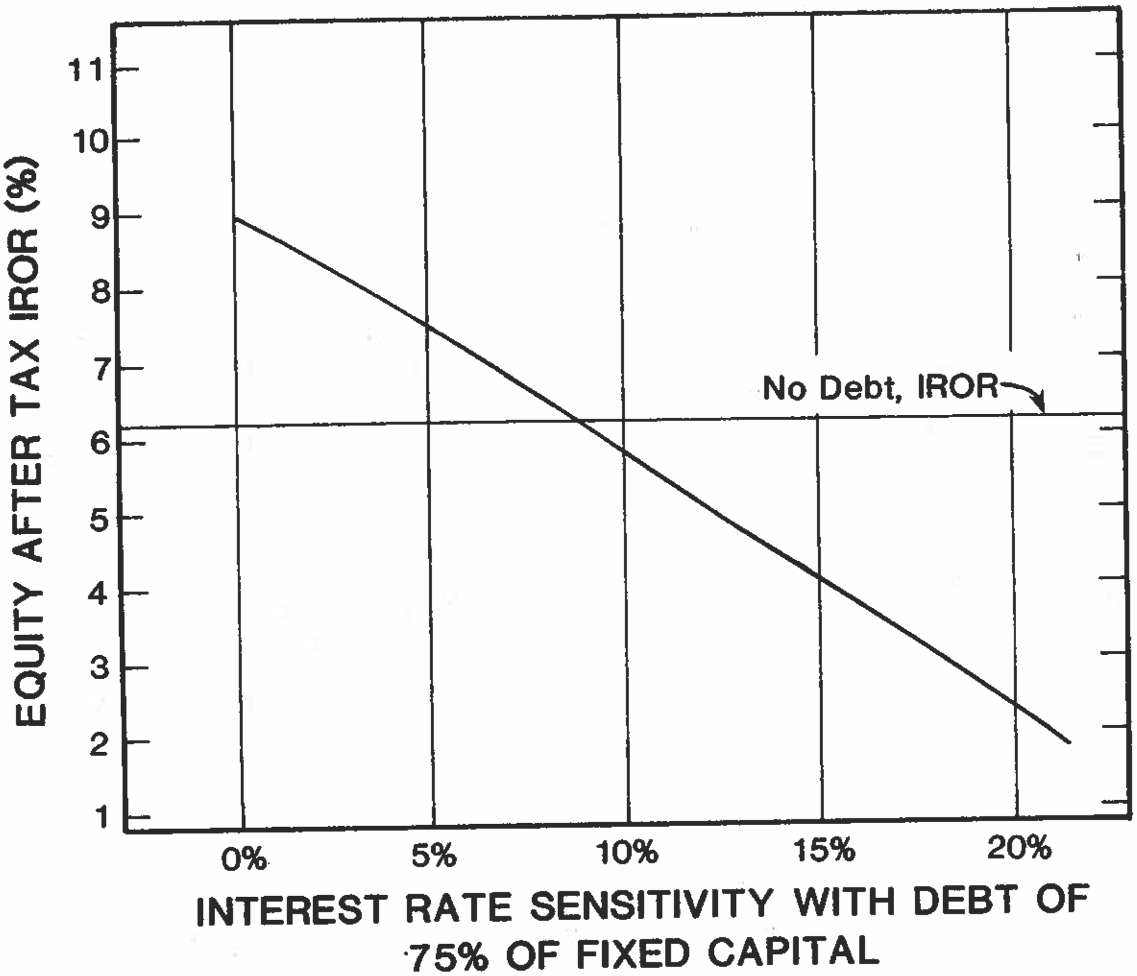


Figure 13. Sensitivity of Return to Interest Rate on Debt

Table 28. Sensitivity of Returns to Metal Price Variations

	METAL PRICE SENSITIVITY					
	All Prices Change		Nickel Change Only		Manganese Change Only	
	+30%	-30%	+30%	-30%	+30%	-30%
Total Investment Funding	1,432.3	1,432.3	1,432.3	1,432.3	1,432.3	1,432.3
Fixed Capital Investment	869.3	869.3	869.3	869.3	869.3	869.3
Net Annual Revenue	681.9	367.5	565.3	484.0	619.5	429.7
Annual Operating Costs	335.8	335.8	335.8	335.8	335.8	335.8
S.L. Depreciation Expense	164.2	164.2	164.2	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0	195.0	195.0	195.0
Before Taxes						
Average Profit	349.1	37.8	235.6	153.1	287.2	99.3
Return on Total Investment	24.37	2.64	16.31	10.69	20.05	6.94
Return on Fixed Capital	40.16	4.35	26.87	17.62	33.04	11.43
Payback on Total Investment	10-6	>26-0	12-8	16-3	11-5	22-2
Payback on Fixed Investment	8-10	>26-0	10-3	12-6	9-6	16-2
Internal Rate of Return	15.93	NEG	10.88	6.37	13.38	2.49
After Taxes						
Average Profit	220.3	37.8	157.9	114.5	186.9	85.4
Return on Total Investment	15.38	2.64	11.03	7.99	13.05	5.96
Return on Fixed Capital	25.34	4.35	18.17	13.17	21.50	9.83
Payback on Total Investment	10-9	>26-0	12-11	16-7	11-8	22-7
Payback on Fixed Capital	8-10	>26-0	10-3	12-6	9-6	16-2
Internal Rate of Return	11.99	NEG	7.90	4.31	9.93	1.43

Note: Dollar amounts in millions of 1982 dollars.
Returns as annual percentage.
Payback periods in years and months.

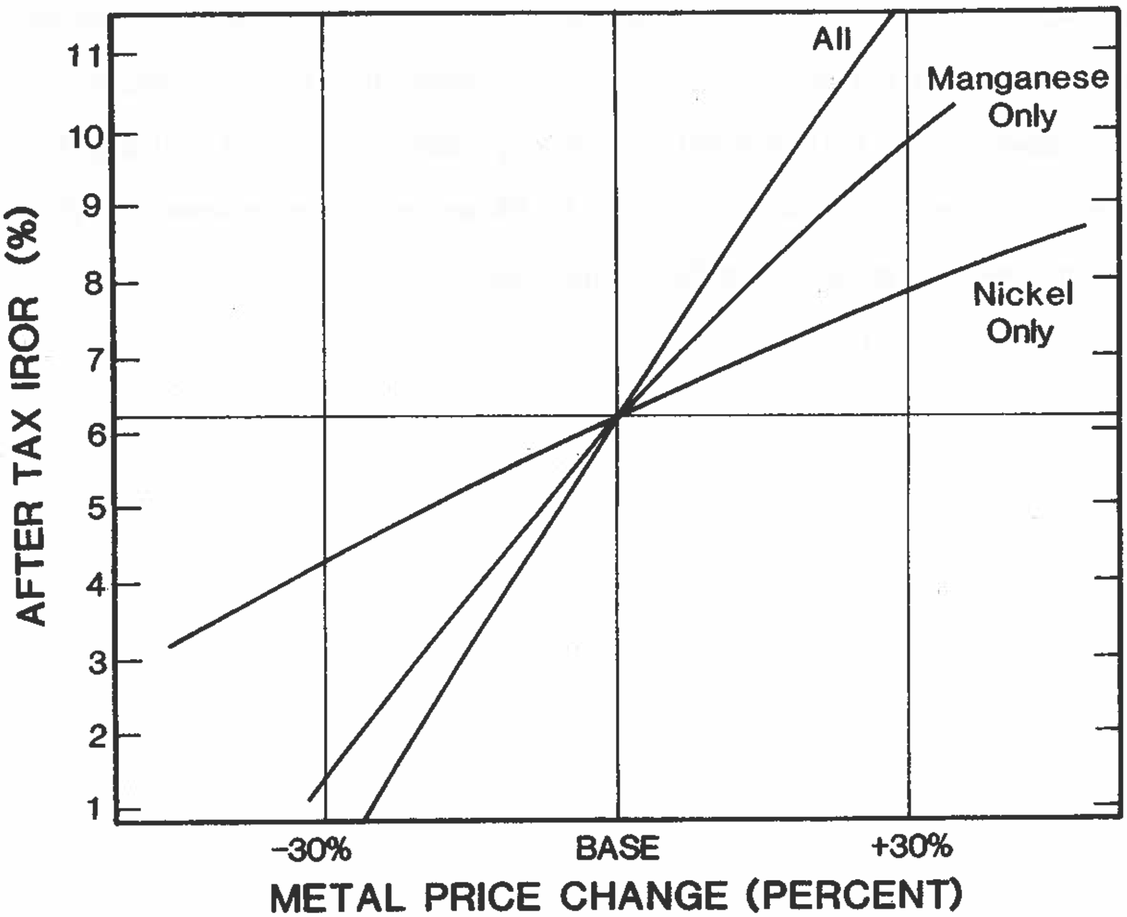


Figure 14. Sensitivity of Return to Metal Price Changes

the standard 46 percent corporate rate assumed in the base case. A short-cut method of depletion computation is commonly used by resource companies, in which effective profits tax rates of 16 to 31 percent are assumed. For this sensitivity study, combined federal and state profits tax rates ranging from zero to 54 percent were assumed. The results are presented in Table 29 and Figure 15.

Table 29. Comparison of Returns with Corporate Tax Rate Variations

	CORPORATE PROFITS TAX RATE SENSITIVITY Tax Rate				
	0%	16%	31%	46%*	54%
Total Investment Funding	1,432.3	1,432.3	1,432.3	1,432.3	1,432.3
Fixed Capital Investment	869.3	869.3	869.3	869.3	869.3
Net Annual Revenue	524.6	524.6	524.6	524.6	524.6
Annual Operating Costs	335.8	335.8	335.8	335.8	335.8
S.L. Depreciation Expense	164.2	164.2	164.2	164.2	164.2
Preparatory Expenditures	195.0	195.0	195.0	195.0	195.0
Before Taxes					
Average Profit	193.3	193.3	193.3	183.5	193.3
Return on Total Investment	13.49	13.49	13.49	12.87	13.49
Return on Fixed Capital	22.23	22.23	22.23	21.11	22.23
Payback on Investment	14-1	14-1	14-1	14-1	14-1
Payback on Fixed Investment	11-1	11-1	11-1	11-1	11-1
Internal Rate of Return	8.76	8.76	8.76	8.57	8.76
After Taxes					
Average Profit	193.3	196.2	156.2	140.3	125.5
Return on Total Investment	13.49	12.30	10.90	9.84	8.76
Return on Fixed Capital	22.23	20.27	17.97	16.14	14.43
Payback on Total Investment	14-1	14-2	14-2	14-4	14-7
Payback on Fixed Capital	11-1	11-1	11-1	11-1	11-1
Internal Rate of Return	8.76	8.16	7.26	6.41	5.55

*Base Case

Note: Dollar amounts in millions of 1982 dollars.
Returns as annual percentage.
Payback periods in years and months.

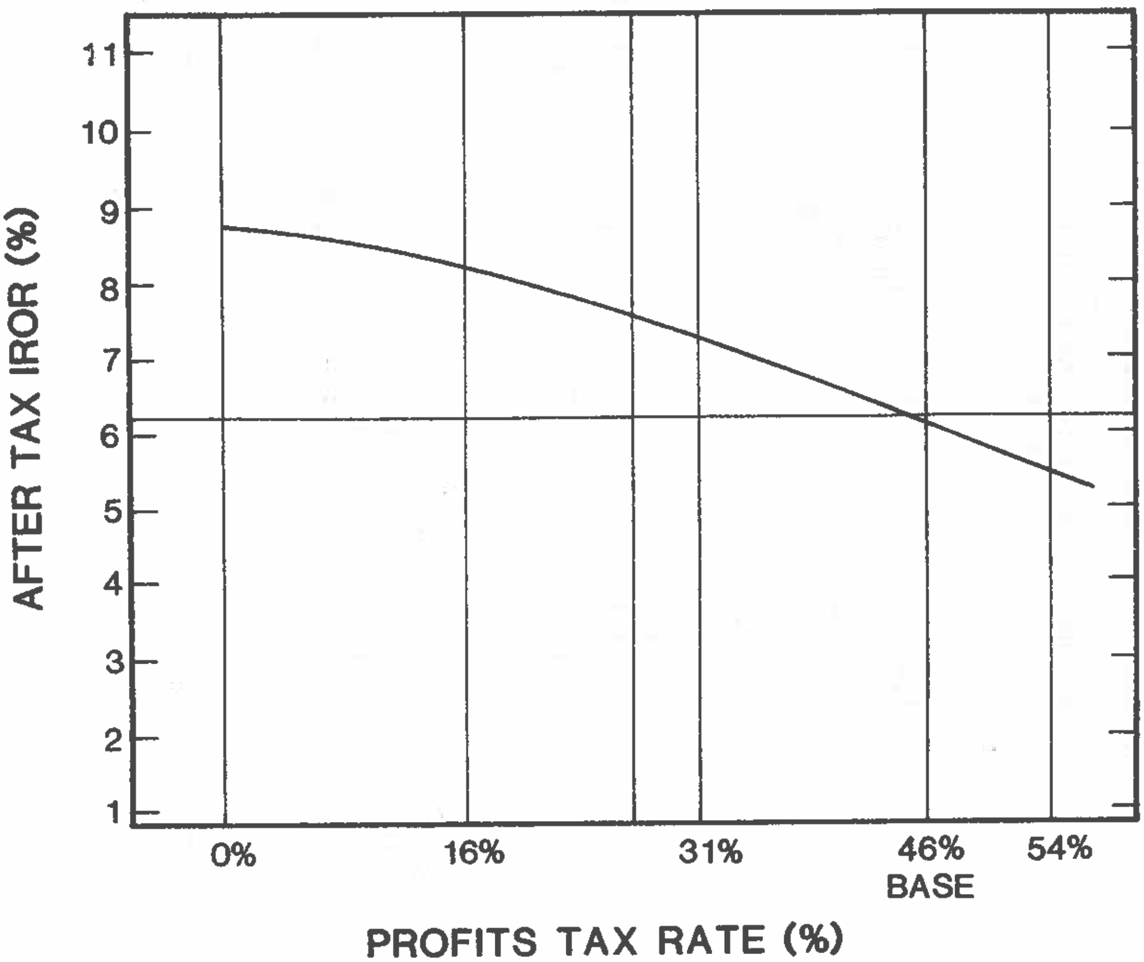


Figure 15. Sensitivity of Return to Corporate Profits Tax Rate

IV

OCEAN ENVIRONMENTAL MONITORING AND SURVEYING

Introduction

Commercial recovery of manganese nodules in the deep ocean may begin in the near future. The mining area will be in the northeastern equatorial region of the Pacific Ocean. After on-shore processing, disposal of the wastes at sea may be desirable to some operators. This section describes potential methods of monitoring possible environmental effects of mining and ocean disposal.

The monitoring and surveying systems described here are directed toward gathering new data to evaluate the long-term effects of extended mining and dumping operations over wide geographic areas. The localized, nearby and short-term activities of test mining operations are to be monitored for their environmental effects. Completed monitoring has indicated that environmental disturbances may not extend far from the active mining ship, or the collector or dumpsite on the seafloor. The monitoring and surveying scope proposed here is designed to verify the hypothesis that extensive, long-term disturbances are limited, by measuring a few relevant physical parameters at the boundaries of the mining and dump sites in the ocean, and performing surveys to measure the effects on the ecosystem in the impacted areas.

The Deep Seabed Mining regulations [8], require monitoring for pretesting, testing and commercial phases of mining operations. Monitoring is also required [13] for the processed waste disposal site under the Ocean Dumping regulations of the Environmental Protection Agency (EPA). This report describes feasible methods to monitor possible long-term environmental effects of commercial mining and ocean disposal that are expected to satisfy regulatory requirements. Each program includes both monitoring and surveying:

the monitoring portion utilizes instrument arrays which record data at a designated site for one year. The surveying portion involves oceanographic sampling to obtain biological, chemical and geological data at certain times of the year. These are used to evaluate long-term effects of mining. The monitoring programs include data measurement for potential environmental impacts, proposed monitoring and surveying equipment needed, hypothetical monitoring schedules and estimates of program costs.

Mine Site Monitoring and Surveying

Areas of Nodule Deposits

Seventy-one percent of the earth is covered by oceans, of which 57 percent consists of water deeper than 2,000 meters, defined as the deep or abyssal sea. Large concentrations of manganese nodules exist on the abyssal plains where sedimentation rates are low (at one to three mm/1,000 years). Manganese nodules occur in patches and vary in abundance and in metal content. The area between the Clarion and Clipperton fracture zones (7°N to 15°N and 120°W to 155°W) was found to be the richest in abundance and in high grade nodules (Figure 16). This area is of great interest to international mining consortia that have developed the technology to lift the nodules off the seafloor in 4,000 to 6,000 meters of water, and filed overlapping claims of the area with the U.S. government.

A full-scale commercial manganese nodule mining operation will mine an area (or areas) approximately equal to 36,000 square kilometers and will be mined over a 20-year period [30]. The sequence for coverage of the mine site is somewhat uncertain, since the minable area can be in any shape, or number of shapes. A mining operation will not strip the entire area; but following the bottom terrain, 10 to 40 percent of the designated area may be unminable

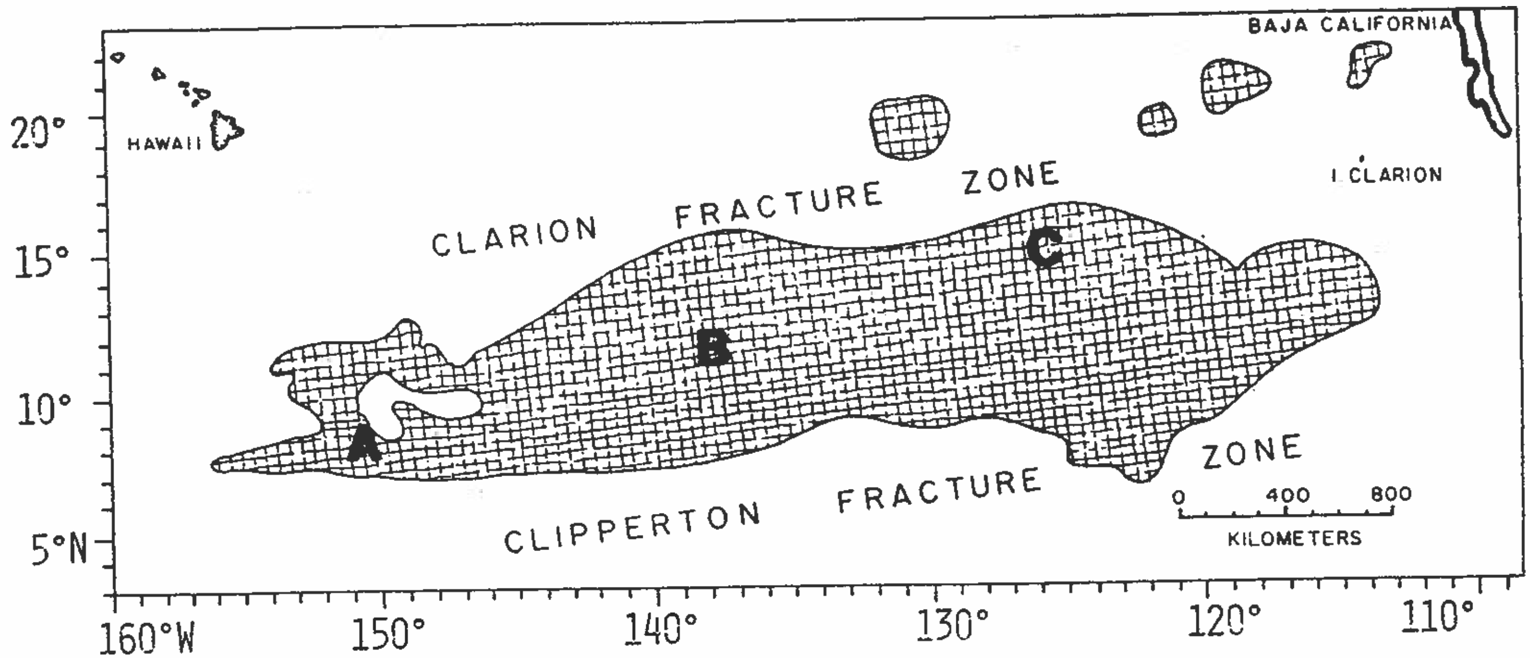


Figure 16. High Density Nodule Areas in the Equatorial Pacific

Areas in the northeastern equatorial Pacific where manganese nodules contain more than 1.8 percent nickel plus copper (modified from McKelvey et al, 1979). Sites A, B, and C were the focal points of Deep Ocean Mining Environmental Study (DOMES) program. The pilot-scale mining tests, subject of DOMES II program, took place near sites A and C.

Source: Deep Seabed Mining Marine Environmental Research Plan due to (a)unfavorable geographic features, (b)inability to control operations accurately or (c)selection only of areas with high-grade nodules. This "patchy" mine site pattern (Figure 17) makes the establishment of a generalized monitoring program a difficult assignment in the abstract.

Licensing and Permiting Procedures

Detailed deep sea mining regulations for exploratory licenses were established under the 1980 Deep Seabed Hard Minerals Resource Act; PL 96-283 [9]. A mining consortium is required to apply for a license to explore and for a permit to mine. Initially, the application for a license deals with a specific site where testing will occur. NOAA assesses the environmental impacts of the proposed ocean test area, and draws up a site-specific environmental impact statement (EIS) using existing data and any supplemental baseline data about the area submitted by the applicant. At least one year prior to small-scale demonstration tests, the applicant must submit data from a baseline study conducted at the designated mining area to establish the site's biological, chemical, geological and physical characteristics. The success of the baseline study depends on the ability of the applicant to identify the critical species, their abundance, habitats and biological processes in order to determine the relevance, feasibility and affordability of future collection of data. As an aid to applicants, NOAA constructed a Technical Guidance Document [31] based on NOAA's previous sampling strategies and analysis of the Deep Ocean Mining Environmental Study (DOMES). Suggested formats for data submission are outlined to aid in quick and proper evaluation of the applicant's baseline information in preparing the site-specific EIS. At this stage, localized short-term effects are redefined, and potential long-term effects are again hypothesized.

For commercial operations to begin, a permit is needed. The licensee

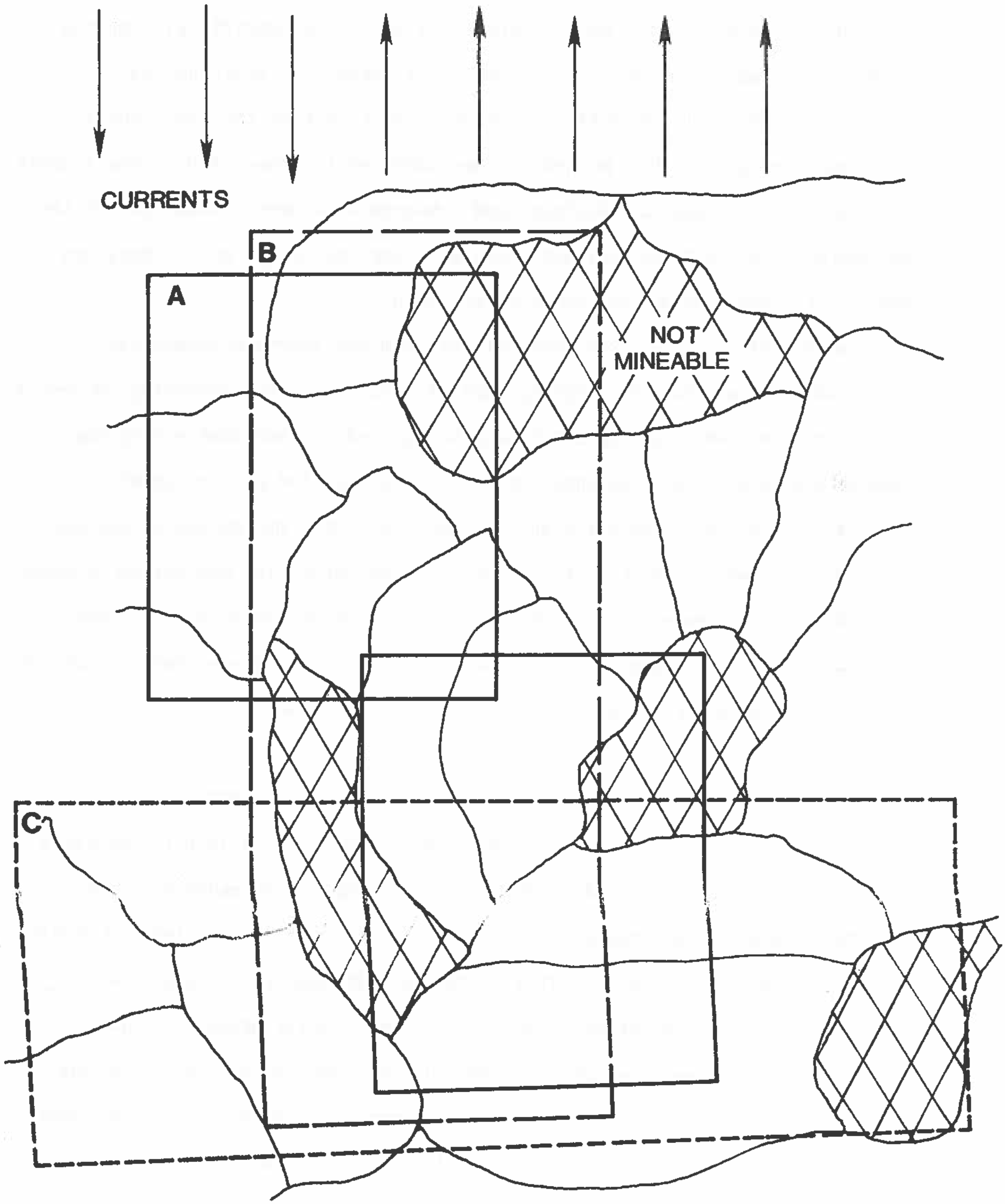


Figure 17. Three Possible Mine Site Configurations

submits the accumulated environmental data and projections of commercial full-scale operations for NOAA to prepare a mine site-specific EIS for the permit. The applicant prepares a commercial production environmental self-monitoring plan for NOAA to approve. The extent of the applicant's self-monitoring plan will be heavily dependent on the one-fifth or small-scale test monitoring results. Approval and issuance of a permit occur before the GO decision to construct vessels and plant, and the costs, until then, are part of the Preparatory and Exploration amount.

Upon approval, the permittee will perform the approved commercial operation self-monitoring program, such as described here, beginning in Year 6 and continuing until sufficient data are acquired to show that mining has negligible adverse environmental effects. Reevaluation of the commercial monitoring plan may take place during the life of the mining operations,and NOAA may approve a reduction in the scale of the mine site monitoring program. Details of the commercial monitoring program and time schedules are suggested in the Monitoring Program section, but these descriptions are those of neither industry representatives nor governmental administrators.

DOMES Study

The National Oceanic and Atmospheric Administration (NOAA) initiated a Deep Ocean Mining Environmental Study (DOMES) from 1975 to 1980 to provide a data base for assessment and prediction of the impacts of manganese nodule mining on deep-sea environments. DOMES I characterized the designated mining area by establishing the biological, chemical, geological and physical baselines prior to operations. In 1978-79, small-scale manganese nodule mining operations were conducted. DOMES II involved the monitoring of the actual mining operations, to observe environmental effects and to supplement the NOAA existing data to enhance capabilities of environmental prediction.

Three sites were designated in the DOMES area, shown on Figure 16. Field studies included upper water layer measurements of currents, primary productivity, and abundance and species composition of the zooplankton and nekton. Temperature, salinity, suspended particulate matter (SPM), nutrients and dissolved oxygen were measured throughout the water column. Bottom currents, abundance and species composition of the benthos, and sediment characteristics were also determined. When the pilot mining operations began, discharge volumes and particulate concentrations of both the surface and bottom sediment plume were measured.

The recovery and separation of manganese nodules affects both the surface and subsurface environment of the seafloor. The upper ten centimeters of the sea bottom and its benthic inhabitants would be removed with the passage of the collector. The benthic plume consists of fine particles, predominantly sediments, rejected by the nodule collector. Photography has shown most of the sediment that settles initially does so in or near the collector track. The fines which remain suspended in the water column, SPM, are carried by any bottom currents that may exist. SPM concentrations have been observed to be as high as 150 μg/liter in the benthic plume, compared with ambient values of <10 μg/liter. The benthic plume is characterized by a thickness of a few tens of meters at a bottom depth of about 5,000 meters. Inhabitants around the collector path will be affected by a benthic plume of sediment, abraded nodules and animal fragments created by the collector. At the surface, a plume of similar composition will be created when the dredged seawater is being discharged from the ship after separating the nodules. NOAA compiled a Programmatic EIS (PEIS), which presents a detailed environmental assessment of mining impacts [30].

The initial environmental concerns and potential impacts of mining are summarized in Table 30-A. The general conclusion of the DOMES report was that only localized, short-term effects occurred around the surface discharge point [30]. However, several long-term impact questions are still unresolved and tentative conclusions need to be verified or refined (Table 30-B) under more realistic mining conditions or over a longer time period. Table 31 lists the uncertain biological impacts and suggests research to evaluate possible mitigation strategies [32].

License Baseline

Ideally, adequate monitoring and surveying programs should develop the capability of assessing and predicting trends in environmental quality and how the mining discharge affects ecosystems. The success of a monitoring program depends on the ability to identify critical species, their abundance, habitats, and processes to determine the relevance, feasibility, and affordability of data collection. Potential environmental effects that are now known to be of long-term concern include the effects of recovery of the benthic community after mining, behavior and feeding of fish larvae and benthos in the plumes, and intertrophic effects.

Results from baseline and one-fifth scale test monitoring, before and during the license phase, are used to predict environmental effects in the site-specific EIS, to be verified by observation during commercial operations. The escalation or reduction of the monitoring program during the testing and commercial phases depends on the results obtained in the applicant's baseline studies and commercial test monitoring. Mining is allowed to continue if no significant effects are obtained. However, if impacts are significant, NOAA has the authority to suspend commercial mining permanently or until the impact has been corrected. NOAA may also change the performance standards of the self-monitoring program as more information is accumulated.

Table 30-A. Summary of Initial Environmental Concerns and Potential Significant Impacts of Mining

Initial Conditions[1] DISTURBANCE	Physico-Chemical Effects	Potential Biological Impacts (remaining concerns in CAPITALS)	POTENTIAL SIGNIFICANCE OF BIOLOGICAL IMPACT: Probability of Occurrence	Recovery Rate	Consequence	Overall Significance
COLLECTOR	° Scour and compact sediments	DESTROY BENTHIC FAUNA IN AND NEAR COLLECTOR TRACK	Certain	Unknown[3] (probably slow)	Adverse	Unavoidable* (uncertain sig.)
	° Light and sound	Attraction to new food supply; possible temporary blindness	Unlikely	Unknown (probably rapid)	Uncertain	None
BENTHIC PLUME	° Increased sediment rate and increased suspended matter ("rain of fines")	° EFFECT ON BENTHOS - covering of food supply	Likely	Unknown[3] (probably slow)	Adverse	Unknown*
		- clogging of respiratory surfaces of filter feeders	Likely	Unknown[3] (probably slow)	Adverse	Unknown*
		- blanketing	Certain	Unknown[3] (probably slow)	Adverse	Unknown*
		° Increased food supply for benthos	Unlikely	Rapid[4]	Possibly Beneficial	None
	° Nutrient/trace metal increase	° Trace metals uptake by zooplankton	Unlikely	Rapid	No detectable effect	None
	° Oxygen demand	° Lower dissolved oxygen for organisms to utilize; mortality from anaerobic conditions	Unlikely	Rapid	No detectable effect	None

Table 30-A. Continued

Initial Conditions[1] DISTURBANCE	Physico-Chemical Effects	Potential Biological Impacts (remaining concerns in CAPITALS)	POTENTIAL SIGNIFICANCE OF BIOLOGICAL IMPACT: Probability of Occurrence	Recovery Rate	Consequence	Overall Significance
SURFACE DISCHARGE Particulates	° Increased suspended particulate matter (sediments, nodule fragments and biota debris)	° Effect on Zooplankton - Mortality	Unlikely	Rapid[4]	No detectable effect	None
		- Change in abundance and/or species composition	Unlikely	Rapid[4]	No detectable effect	None
		- Trace metal uptake	Unlikely	Rapid	Locally Adverse	Low*
		- Increased food supply due to introduction of benthic biotic debris and elevated microbial activity due to increased substrate	Unlikely	Rapid[4]	Possibly Beneficial	None
		° Effect on adult fish	Unlikely	Rapid[4]	No detectable effect[2]	None
		° EFFECT ON FISH LARVAE	Uncertain (Low)	Uncertain (probably Rapidid)	Uncertain	Low*
	° Oxygen Demand	° Lower dissolved oxygen for organisms to utilize	Unlikely		No detectable effect	None
	° Pynocline accumulation	° Effect on primary productivity	Unlikely	Uncertain (probably rapid)	Unknown (probably undetected)	Low
	° Decreased light due to increased turbidity	° Decrease in primary productivity	Certain	Rapid[4]	Locally Adverse	Low
SURFACE DISCHARGE Dissolved Substances	° Increased nutrients	° Increase in primary productivity	Very Low	Rapid[4]	No detectable effect[2]	None
		° Change in phytoplankton species composition or introduce deepsea microbes or spores to surface	Very Low	Rapid[4]	No detectable effect[2]	None

Table 30-A. Concluded

Initial Conditions[1] DISTURBANCE	Physico-Chemical Effects	Potential Biological Impacts (remaining concerns in CAPITALS)	POTENTIAL SIGNIFICANCE OF BIOLOGICAL IMPACT			
			Probability of Occurrence	Recovery Rate	Consequence	Overall Significance
SURFACE DISCHARGE Dissolved Substances (Continued)	° Increase in dissolved trace metals	° Inhibition of primary productivity	Very Low	Rapid[4]	No detectable effect[2]	None
	° Supersaturation in dissolved gas content	° Embolism	Very Low	Rapid	No detectable effect[2]	None

[1]Includes characteristics of the discharge and the mining system.
[2]Based on experiments/mesaurements conducted under DOMES.
[3]Years to tens of years, or longer.
[4]Days to weeks

Uncertain = some knowledge exists; however the validity of extrapolations is tenuous.
Unknown = very little or no knowledge exists on the subjects; predictions mostly based on conjecture.
*Areas of future research.
SPM = suspended particulate matter.

Table 30-B. Summary of Initial Environmental Concerns and Potential Significant Impacts of Mining

LICENSE PHASE		PERMIT PHASE		
Mitigation	Monitoring	Possible Mitigation	Monitoring	PARAMETERS OF CONCERN
None	Study tests	Premature	Study initial operations	Natural history; recolonization; subarea mortality
None	Verify predictions during tests	Premature	Premature	Community size, structure, and population oscillations for scavengers; behavior of benthic organisms
Proximity of sites; stable reference areas	Study tests	Control dispersion; require compact shape of site	Study initial operations	Natural history; recolonization; fate of plume (suspended particulates); mortality away from subarea; mine site shape; proximity of mine sites
None	Verify predictions during tests	Premature	Premature	SPM concentration; dissolved oxygen of bottom water
None	Verify predictions during tests	Premature	Premature	Chemistry of bottom and interstitial waters
None	Verify predictions during tests	Premature	Premature	Dissolved oxygen for bottom water
None	Verify predictions during tests	Premature	Premature	SPM concentration and zooplankton mortality
None	Verify predictions during tesets	Premature	Premature	Nutrient content of surface waters; SPM concentration; zooplankton mortality and species changes
None	Surface discharge and zooplankton in and around plume	Premature (could retain nodule fines on ship if necessary or discharge beneath surface	Surface discharge	Nodule fines in discharge; uptake in zooplankton tissues; trace metal concentrations in surface water

Table 30-B. Continued.

LICENSE PHASE		PERMIT PHASE		
Mitigation	Monitoring	Possible Mitigation	Monitoring	PARAMETERS OF CONCERN
None	Verify predictions during tests	Premature	Premature	SPM concentration; dissolved oxygen in surface waters
None	Verify predictions during tests	Premature	Premature	SPM concentration; effects on feeding and spawning of tunas
None	Fish larvae in and around plume	Premature (could discharge at depth if necessary	Premature	Fish larvae mortality; dissolved metal content of discharge
None	Verify predictions during tests	Premature	Premature	Dissolved oxygen of surface waters, SPM concentration
None	Verify predictions during tests	Premature	Premature	SPM concentration and settling velocities
None	Verify predictions during tests	Premature	Premature	SPM concentration; light attenuation values; particles settling rates
None	Verify predictions during tests	Premature	Premature	Nutrient content of discharge
None	Verify predictions during tests	Premature	Premature	Nutrient content of discharge; changes in species composition; rate of silicate uptake by phytoplankton
None	Verify predictions during tests	Premature	Premature	Dissolved trace metals in discharge; SPM concentration.
None	Verify predictions during tests	Premature	Premature	Fish mortality; dissolved O_2 content of plume and ambient waters

Source: Office of Ocean Minerals and Energy, September 1981 [30].

Table 31. Potential Biological Impacts and Supporting Research to Evaluate Possible Mitigation Strategies

Potential Biological Impacts	Potential Significance*	Examples of Possible Mitigation Strategies	Supporting Research
Fish larvae feeding	Uncertain	Premature	° Determine occurrence ° Determine potential year class effect
Destruction of benthic in collector track	Unavoidable	Premature	° Evaluate effect on benthic community
Smothering and starvation of benthos	Unknown	Varying mining pattern	° Monitor recolonization following disturbance
		Control dispersion of benthic plume ("Rain of Fines")	° Identify factors important in recolonization ° Evaluate effectiveness of various mining strategies in minimizing impact ° Develop capability for long-term monitoring of suspended particulate matter concentrations at mine site boundaries

*Uncertain is used when prediction is based on some knowledge, although insufficient. Unknown is used when prediction is primarily conjecture, based on minimal knowledge.

Source: Office of Ocean Minerals and Energy, June 1982.

A manganese nodule mining operation is expected to average 300 days per year. As the collector is towed along the seafloor, it will gather manganese nodules and the upper few centimeters of sediment in a path perhaps 20 meters wide. Under expected operating conditions, the collector may cover 100 kilometers daily in closely spaced tracks, possibly recovering some 5,000 tonnes (dry weight) of nodules [17]. Daily discharge rates of sediment are estimated to be 1.6×10^3 metritonnes (dry) at the surface and 5.2×10^4mt (dry) at the bottom [34]. Based on DOMES measurements, sediment dispersion models for a commercial mining operation predict a surface plume 85 kilometers long and 10 to 20 kilometers wide. The benthic plume created by the collector may increase sediment loads detectable to distances as far as 100 kilometers from the mining region. Slow bottom currents will increase suspended sediment loads in an area and are expected to range from 3,000 to 5,000 square kilometers for as long as one year [29].

Benthos Monitoring and Surveying

Major concerns of the monitoring program should be directed on the benthos. The deep sea is a constant environment whose populations are limited by the food supply filtering down from the upper water column. Reproductive potentials, recruitment rates and individual species populations are low, but species diversity is high. Very little data are available on life histories of the deep-sea benthic species [22].

Direct mortality of benthic organisms is inevitable in the path of the collector. The significance of this mortality rate on the survival of a benthic community under full-scale mining operations has not yet been measured. Sediment dispersion models demonstrate that the bulk of the suspended sediment will be deposited within a few hundred meters of the collector [29]. However, the fine particles with slower settling velocities can potentially cause significant mortality to epibenthic organisms in the surrounding areas by smothering them [26]. Also, burial or dilution of the thin surficial food layer could starve epibenthic fauna.

NOAA found that the benthic plume had an adverse impact on benthic populations but could not determine the degree of harm. Factors that need to be studied during long-term monitoring are recolonization rates, species recolonizing, especially epifaunal and infaunal invertebrates, and how the consequences affect the food web. Perturbations in the deep sea probably cause changes in the benthic community, but because biological data are inadequate and because of the nature of the environment, any impacts would be difficult to detect [26]. Therefore, intense, long-term biological sampling of the benthos and the overlying water column should provide the crucial information needed to determine chronic impacts of mining.

Information on species composition, spatial variability and density is obtained from bottom sampling, photography and videotape. A modified USNEL box corer sampled well in multisubstrates because of its weight and adjustable bite [23]. Because the benthos is so sparsely populated, the bite was increased to 0.25 square meters, which also minimized the boundary effects and produced a relatively undisturbed sample. Initially, at least three samples should be taken at each survey station. Samples are elutriated through a 300-μ mm screen, which separates the sediments from the animals [38]. Samples then are fixed in buffered formalin for two days, preserved in 70 percent ethanol and stained with rose bengal. Each sample should be sorted by major taxon down to feeding guilds within families [15]. Further details of sampling, processing, and statistical analysis can be found in [21].

Arrays of monitoring devices will be used to measure the physical parameters at the ocean bottom at the deep-sea mine site. Moored package arrays of vector-averaging current meters and beam transmissometers can be used to record bottom currents and suspended particulate matter. Beam transmissometers are used because they can consume little power [27]. Water will be sampled for nutrient, heavy metal and trace metal determination by an autoanalyzer and an atomic absorption spectrophotometer onboard the survey ship.

Surface Surveying

The existence of the particulate surface plume causes temporary, localized effects on the upper water column ecosystem [33]. Potential impacts on fish larvae remain uncertain from the DOMES studies. Finfish and their larvae occur throughout the DOMES area. The Eastropac expedition [1] showed that only one percent of the larvae sampled were epipelagic species, such as tunas. Tuna larvae are found in the uppermost layer of the water column. Particulate matter settling through the surface layers may increase larval mortality. Bongo (505- m mesh) and neuston nets can be used to sample fish larvae. Triplicate oblique tows of the top 200 meters of the water column should be taken to secure larvae samples. Flowmeters determine the volume of water filtered. Detailed sampling procedures and data analysis can be found in reference [39].

Long-term bioaccumulation effects on larvae and fish in the upper water column are also unknown. Organisms could ingest or absorb trace metals introduced from the abrasion of manganese nodules from the sea floor. That zooplankton could absorb trace metals from ingested nodule fragments resulting in bioaccumulation has been hypothesized [24]. This suggests a remote possibility that bioaccumulation could affect commercial fish catches, and eventually man, but this has not been demonstrated or verified, although it has been attempted [3].

Fish of commercial importance, such as the tunas and billfish, are of minor concern, as increased concentrations of particulates could clog the gills of fish in the mining area. In laboratory studies, adult tuna demonstrated their ability to avoid turbid areas [33]. Midwater trawls should be used to sample finfish. Tuna can be sampled effectively on commercial tuna boats using purse seines and hydroacoustic equipment. Examination of the gills will reveal whether suspended particulates affect respiration and feeding. Analysis of muscle and liver samples can indicate possible toxic effects from trace metal uptake.

Description of the Monitoring Equipment

The system of monitoring instruments described here is intended to measure and evaluate long-term, perhaps as long as 20 years, effects on the marine environment at the mining site. Fifteen instrument arrays will be placed in the areas adjacent to collector paths, in the direction of the currents.

The proposed instrument array for the mining site includes a water sampler, specific dissolved metal ions recorder, current meter and data recorder, and beam transmissometer. The equipment selected is the Model 590 self-contained, digital recording, data acquisition system from Interocean Systems, Inc. This system's transmissometer measures light transmission, which is directly related to the level of particulates suspended in the water column. Bio-fouling is inhibited by the copper-nickel alloy sensor used. Welded stainless steel housings, non-corrosive materials, and anti-fouling materials are used in the construction of the Model 590.

The benthic current will be measured with a vector-averaging acoustic current meter from Neil Brown Instrument Systems, Inc. The instrument will measure and record the vector magnitude (± 1 cm/s) and vector direction (± 5

degrees). An averaging interval of one to fifteen minutes may be used with the recording interval at every ten averaging intervals. Continuous operation of the meter, including the internal vector-averaging, eliminates the sampling errors common with burst sampling meters. Current velocity is measured using the phase difference between two simultaneous signals, each distinctly affected by the current. A magnetometer-type compass gives the direction of the current relative to magnetic north.

Optional equipment, including salinity and temperature instruments, is available with this package, but not required at deep water mining or disposal sites. Salinity is computed automatically from conductivity and temperature measurements. A bridge network of resistors and thermistors matches conductivity as a function of temperature and a constant to salinities between 0 and 45 parts per thousand. Temperature is measured by a linearized thermistor.

Use of the recommended sensors achieves extensive monitoring of both areas. Sensors are easily added or removed. The probe is constructed out of non-corrosive stainless steel.

The Model 590 programmable data logger stores as many as eight parameters on a cassette tape. A minimum recording periodicity of six hours is recommended to insure that peak SPM values will be measured when the mining vessel is close to the system. In addition, measuring could be triggered when the level observed exceeds a pre-set minimum. The data logger provides a recording periodicity of 15 minutes to 12 hours. Recording capacity is 180,000 data words. A recording duration of 0.5 seconds to 2,048 minutes can be selected; the maximum recording duration will be determined to assure that the data logger's battery will have the required one year life.

An acoustic instrument release system is recommended. The Interocean

Model 1090D Acoustic Transponding/Pinger Release includes a release function, a command rearm function and a transponder for positioning. Two Model 1090D units will be used with each Model 590 system to ensure recovery; experience may prove that only one release device is necessary.

Most ocean buoyancy packages are not designed for use at depths of 5,000-6,000 meters. Steel spheres have a maximum depth capability of less than 5,000 meters. Glass spheres are used to depths of approximately 7,000 meters and are chosen for this purpose. Each Benthos Model 3752-4 low-drag buoyancy package, rated to depths of 6,700 meters, consists of four 17-inch-diameter glass spheres in a streamlined, molded yellow polyethylene housing, providing 210 pounds of buoyancy. A mounted tailfin orients the unit in the current direction to reduce drag. Two buoyant units will be used with each instrument monitoring system, providing 420 pounds of buoyancy.

Concrete anchors are used in the monitoring system so that the moored system would have a net negative buoyancy of 150 pounds. A mooring set-up for the monitoring system is shown in Figure 18.

Monitoring and Surveying Program

To determine short- and long-term environmental impacts, monitoring and surveying may occur during the entire 20-year lifespan of the commercial mining operation. First-generation mining consortia may be permitted to develop at least a 36,000 square kilometer plot of the seabed for manganese nodule extraction. The sequence of coverage of the mine site is somewhat uncertain because the minable area can be of any shape or number of shapes, and topographic features will cause deviations from proposed mining paths. This "patchy" mine site pattern, due to the varying topography and nodule densities (Figure 17) makes the establishment of a monitoring program site-specific. Assuming a 30 to 50 percent area loss due to the reasons stated

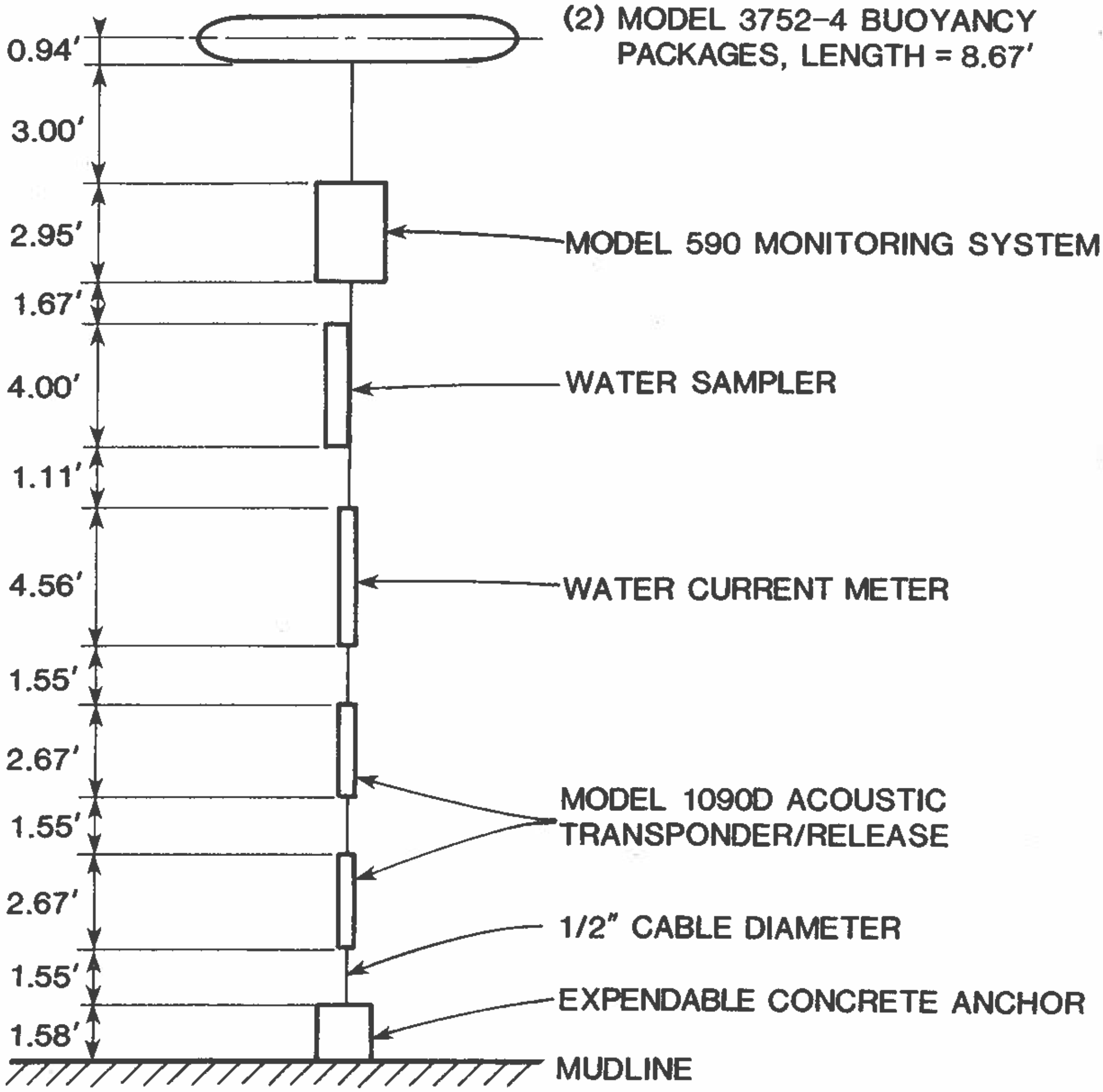


Figure 18. Mooring Set-Up for the Monitoring System

above, a 60,000 square kilometer plot is used to illustrate the instrument array arrangements and give the mine site some arbitrary dimensions.

An ideal monitoring program could be defined if the mine site were rectangular, if the annual mining area were equally divided into 20 sections (one for each year), and if physical parameters (such as currents) were uniform over the entire mine site, as in Figure 19. Instrument arrays could be placed downcurrent of the mining area, for example in three rows 5 kilometers apart, and within rows the arrays could be 27.5 kilometers apart, as shown in Figure 20. Placing three arrays upstream of the mining area would be effective if the currents ever reverse direction.

Because very little seasonality exists in the deep sea [22], surveys would be conducted twice a year at each designated survey station, including a reference station along the downstream site boundary, as shown in Figure 20. Data from the reference station would be compared with the data from the instrument arrays to estimate the arrays' accuracy.

Information gathered from each data recorder should be identified as to its exact bottom location as can be determined by the ship's position relative to the transponder's signal. Records will be kept for each year of deployment and compared with the licensee or permitee's baseline measurements. Perturbations from ambient conditions should be carefully identified to determine any long-term effects. If no perturbations are measured for a certain instrument location over time, discontinuing monitoring at that location should be considered. Annual operating costs would then decrease and no data lost. However, if any extreme perturbations from the baseline noted, efforts should be concentrated upon discovering their source, perhaps by installing more instrument arrays nearby or by comparing with survey data taken in the area under concern. Once the source has been located, positive

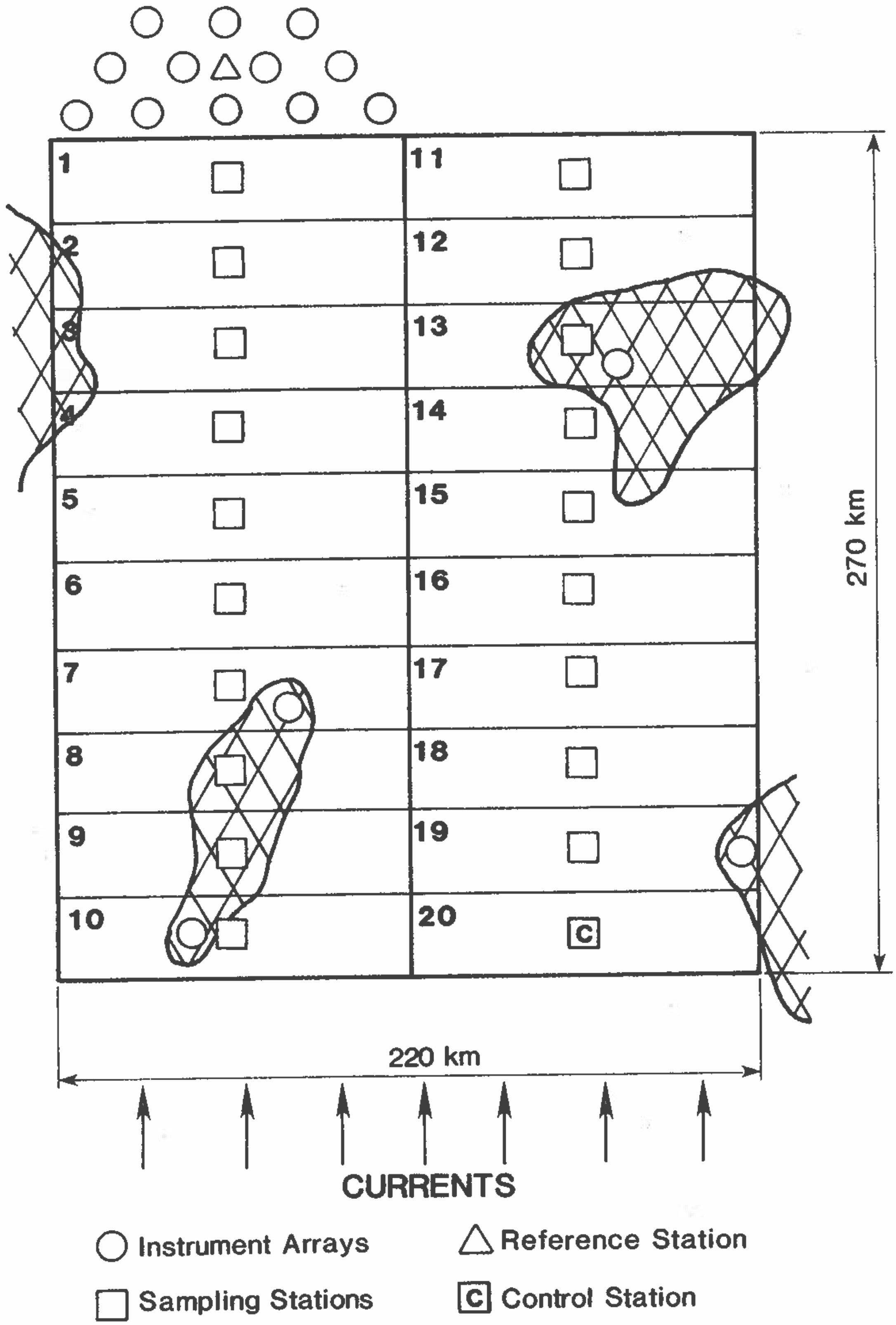


Figure 19. Idealized Twenty Year Mining Area

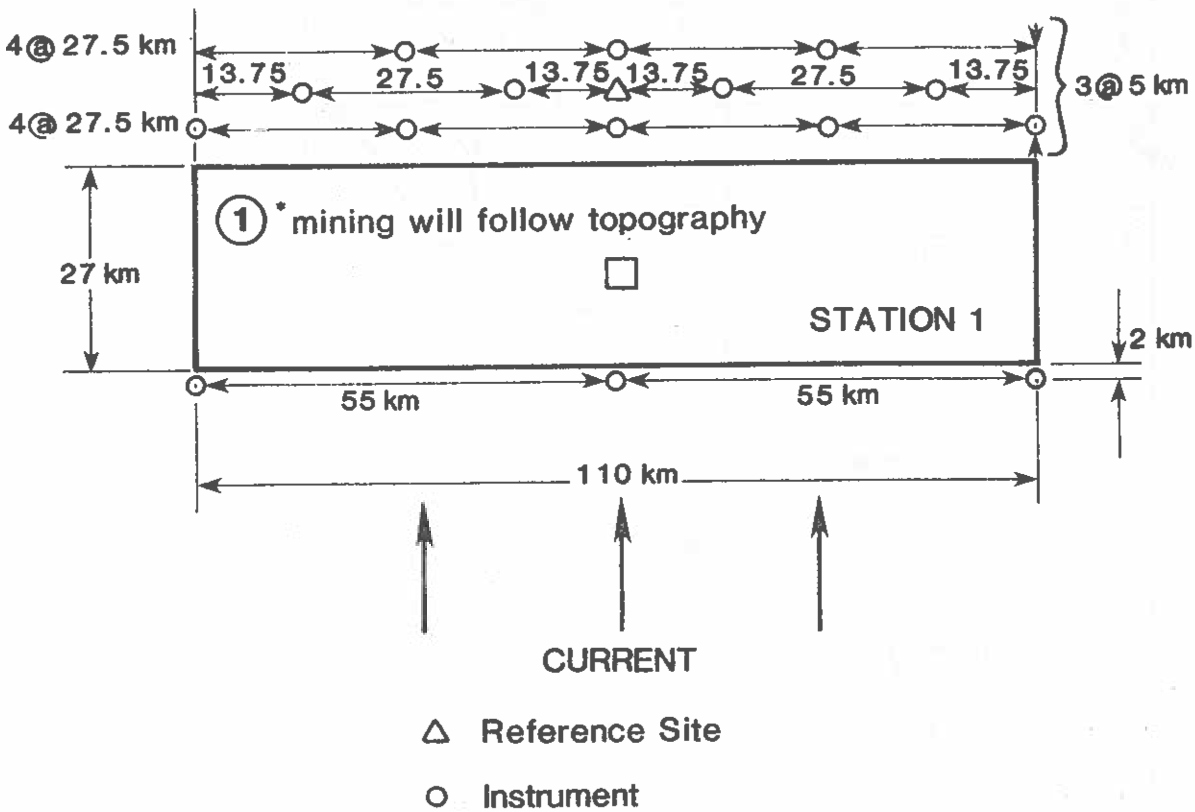


Figure 20. Idealized First Year Mining Area

measures may be taken to delineate the effects. Because in this idealized program (Figure 19) the 20th site would be mined last, this station could act as a control site.

Full-scale surveys of physical, chemical, geological and biological parameters would occur as proposed in the monitoring schedule in Table 32. Data will be evaluated each year to determine if the arrays are recording accurately. If so, the surveys could be reduced to sampling biological and chemical data only. Table 33 summarizes activities in the full- and reduced-scale surveys. After a good data base has been established by Year ten after GO, further reduction in the number of sampling stations might well provide adequate information of the deep-sea mining environment. Figure 21 gives a possible sampling station arrangement for later Years 11 to 20.

The program described above is idealized but can act as a model for more realistic mine sites. If first generation mining plots were proposed in two separate but contiguous sections of seabed, as shown in Figure 22, there could be three approaches to monitoring the two areas. In the first approach, the whole mining area (I and II) can be monitored, requiring a large number of arrays and sampling sites. For the second approach, the portion of the mining area being mined first (such as area I) could be monitored, as shown in Figure 23, as a 'representative' data base for assessing mining impacts. In the third approach, only the area currently being mined could be extensively monitored and only a few designated sites sampled in the other plots (Figure 24).

If the mining area is rectangular or compact in shape, and therefore nearly ideal, monitoring would not require a large number of instrument arrays. However, realistic mine sites are more spread, represented by Figure 22, and require many more arrays around the periphery, depending on the

Table 32. Mining Site Monitoring Program Schedule

Year	Activity
5 to 10 years Prior to GO, before License	Baseline Study: full-scale study to obtain site-specific oceanographic data for license application requirements and site-specific EIS.
1 to 5 years Prior to GO, after Licensed, before Permit	Conduct monitoring program for demonstration testing, and prepare self-monitoring program for commercial operations. Are environmental predictions verified? Yes - Continue proposed or reduced monitoring program. No - Continue proposed or change proposed monitoring program.
Year 5 after GO, after Permit	Set up instrument arrays for commercial mining
Year 7 after GO	Reduce Surveys if approved - 1 or 2 per year. - retrieve data and maintain arrays annually. - collect biological data - collect chemical data
Year 10 after GO, to end of mining	Reduce Monitoring program, if approved to one per year. - retrieve reduced data and maintain arrays annually. - collect reduced biological data. - collect reduced chemical data.

Table 33. Survey Contents at Commercial Mining Site

Full-Scale Surveys* (biannually)

Physical Measurements - at bottom only

	Item	Equipment
1	Current measurements	Current meters
2	Salinity with depth	CSTD
3	Temperature with depth	CSTD
4	Meteorological data	Standard shipboard
5	pH	Water bottle samples
6	Redox	Water bottle samples
7	Dissolved oxygen	Water bottle samples

Geological Measurements - at bottom

1	Particulate suspension	Beam transmissiometer

Chemical Measurements - at bottom and surface

1	Trace metals, toxic elements, and heavy metals in water column	Water bottle, atomic absorption spectrophotometer
2	Trace metals, toxic elements, and heavy metals in sediments	Box corer, atomic absorption spectrophotometer
3	Dissolved nutrients	Autoanalyzer, water bottle samples

Biological Measurements

1	Fish effects	Midwater trawl
2	Larvae and plankton effects	Bongo and neuston
3	Benthic effects	Box corer (0.25 square meter)

* Annual instrument array data pick-up and maintenance also will take place on surveys.

Table 33. Concluded

Reduced Surveys[1] (biannually initially, reduced to annual surveys)

Biological Measurements - at bottom and surface

	Item	Equipment
1	Fish effects	Midwater trawl
2	Larvae and plankton effects	Bongo and neuston
3	Benthic effects	Box corer

Chemical Measurements - at bottom and surface[2]

	Item	Equipment
1	Trace metals, heavy metals and toxic elements in water column	Water bottle, atomic absorption spectrophotometer
2	Trace metals, heavy metals and toxic elements in sediment	Box corer, atomic absorption spectrophotometer
3	Dissolved nutients	Autoanalyzer, water bottle samples

Physical Measurements

	Item	Equipment
1	Meteorological data	Standard shipboard

[1]Annual instrument array data pick-up and maintenance also will take place on surveys.

[2]Number of chemical analyses is dependent on earlier results of test monitoring, and may prove negligible effects occur from mining activities.

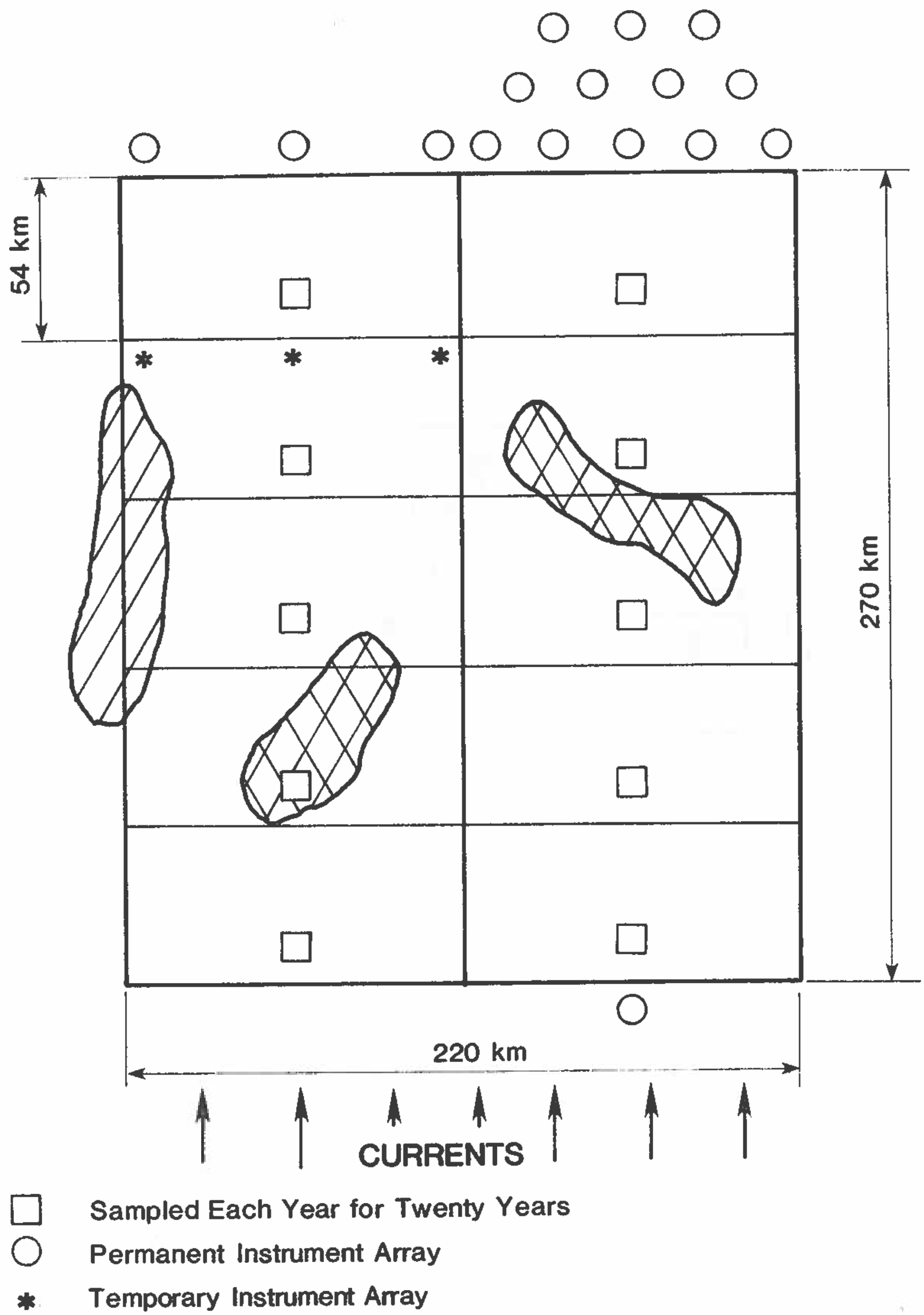


Figure 21. Idealized Station Plan for Years 11 Through 20

direction of the currents. The closer the spacing between the arrays, the better the spatial correlations. However, monitoring costs increase with perhaps few benefits resulting.

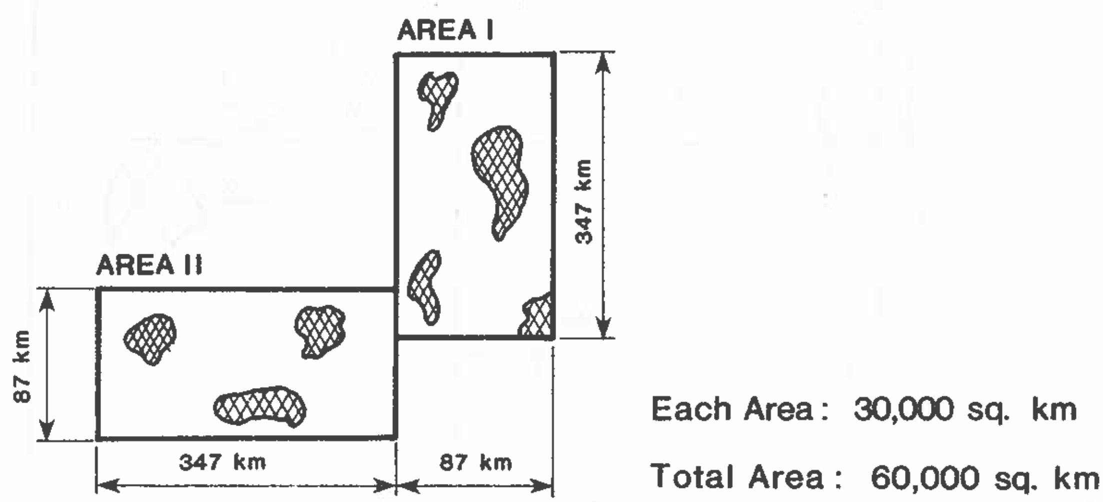


Figure 22. Hypothetical "Realistic" Mine Site

In the second approach, Figure 23, intense monitoring of a designated portion of the mine site will increase the effectiveness of the sampling program. The area mined in the first ten years will provide data of benthic community succession patterns during the 20 years. After year one, station one recovery rates will be monitored for the next 19 years while the following stations are mined and their recovery rates also observed. More effort placed in monitoring one area to obtain a 20 year record may provide more information than effort put in monitoring two areas to obtain two ten year records and a

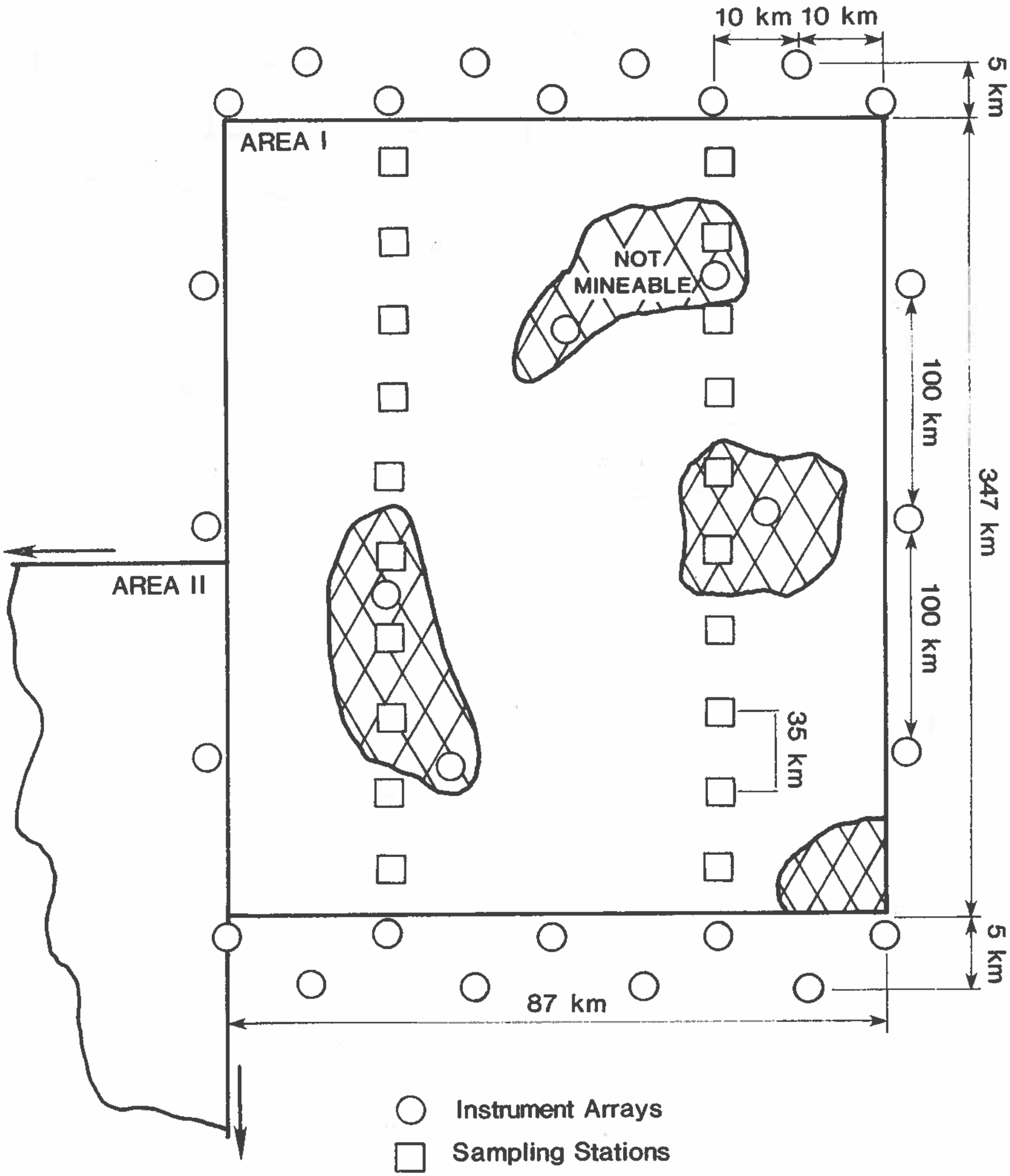


Figure 23. Array and Sampling Arrangement Second Approach

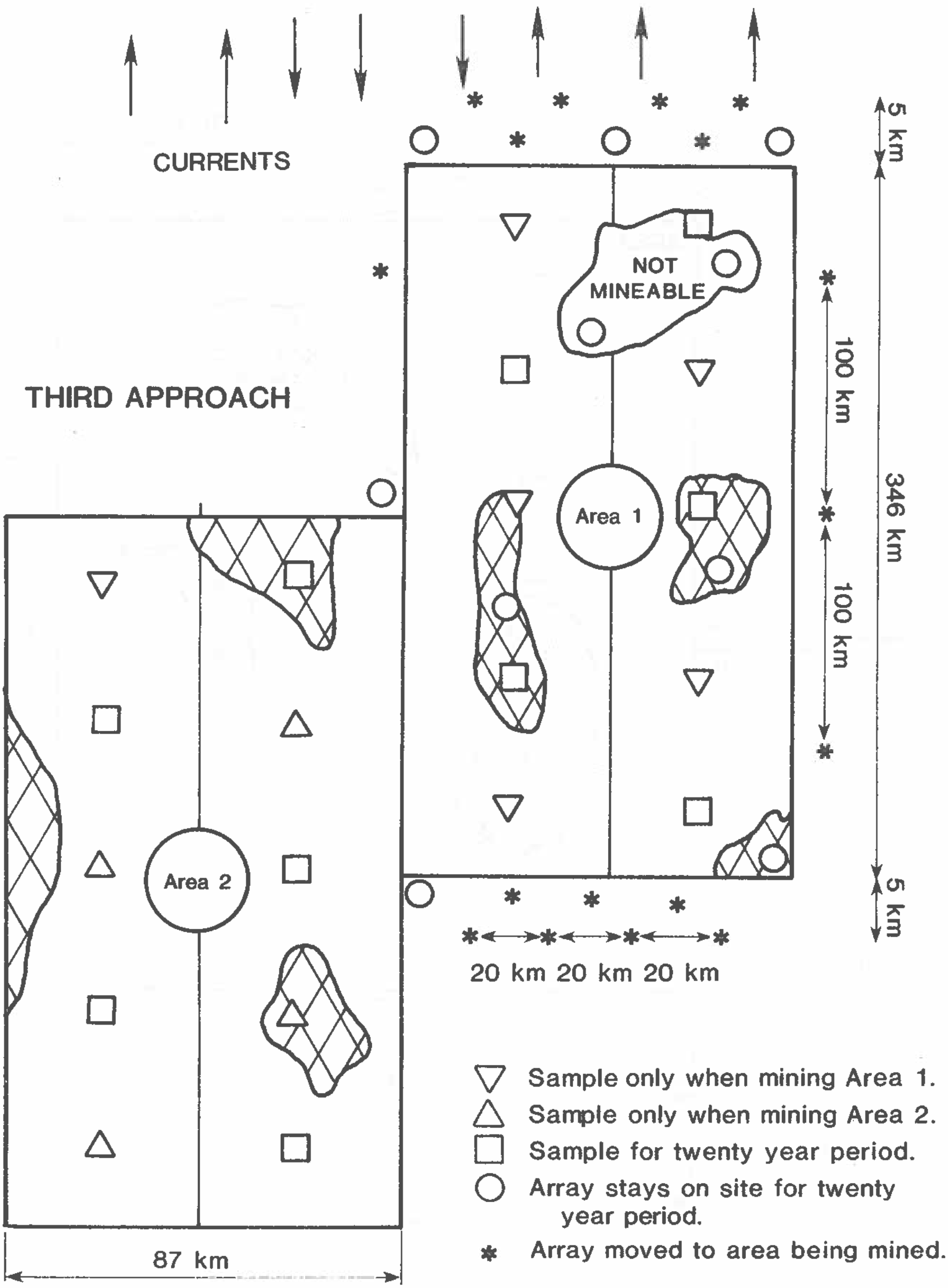


Figure 24. Array and Sampling Arrangement Third Approach

weak 20 year record. The second approach would provide a good data base for long-term assessments of perturbations in the deep sea.

The third approach, Figure 24, is a compromise between the first two approaches. Only the area being mined is intensely sampled. A few designated sites in the contiguous area are sampled each year. Overall, a complete 20-year successional record is obtained for 10 stations, while the other 10 stations will have 10-year records. The advantage of this approach is the spatial coverage of the sampling stations. Arrays can be moved from Area I to Area II, leaving a few designated sites to be monitored. An unminable area is the ideal place to moor an array within the mine site. Approach Three is a more realistic program for monitoring the entire area than Approach One because the ocean is not a homogeneous body of water.

The scale at which the monitoring program continues during mining depends on evaluation of the accumulated information. Consistent verification of previously obtained data would lead to revising and reducing the required monitoring for that site. Inconsistent data would lead to either a continuation of the monitoring program at the same scale or at a revised escalated scale, or suspension of operations altogether.

Cost of Mine Site Monitoring and Surveying

The instruments and buoyancy package will be deployed for one year and then recovered (except for the anchor) for data acquisition and recalibration. Another set of instruments with a new anchor will be placed for the second year, while the original units are maintained. Thus two sets of units will require deployment in alternate years. The total deployed equipment cost is estimated as follows:

Table 34. Mine Site Monitoring Instrument Costs

Unit	Unit Cost	Number	Total Cost
Buoyancy	2,000	60	$ 120,000
SPM and Recorder	40,000	30	1,200,000
Current Meter	11,700	30	351,000
Acoustic Release	8,000	60	480,000
Water Sampler	500	30	15,000
Hardware	200	30	6,000
Anchors	100	30	3,000
	INSTRUMENT ARRAY COST		$2,175,100

Surveying costs are estimated on the assumptions that a research vessel will be employed for a three-week voyage for each survey, twice a year, and that total crew effort will be about six weeks per voyage, allowing for travel and equipment servicing. Some expensive, specific equipment would be acquired for monitoring and surveying, but the total capital cost for box corers, trawls, television and photographic equipment, spectrophotometer, etc., would be small compared to that for other sectors. Therefore the $2.2 million capital costs for the instrument array were increased by $800,000.

The survey operations would require replacement of anchors, acoustic beacons and lost equipment; charter of a 150-foot research vessel; specimen and data storage; analytical equipment; laboratory analyses and reports; reports to the government; and maintenance.

In total, these operating costs are not likely to exceed $350,000, in 1982 dollars per voyage covering 15 sites on each voyage, and 15 instrument arrays recovered and replaced per voyage. The land laboratory costs would total about $750,000 annually, bringing total operating costs to $1.5 million.

Disposal Site Monitoring and Surveying

Disposal Site Options

Ocean disposal of processed manganese nodule wastes may be economically desirable to mining consortia and environmentally preferable to disposal on land. The vastness of the ocean and its high tolerance characteristics makes the ocean an ideal receptacle for return of the unused portion of the nodules. Environmental considerations include bioaccumulation of chemicals in deposit feeding organisms, substrate alterations, direct toxicity, effects on behavioral and feeding patterns of organisms, effects on primary production, and intertrophic effects. The relative significance of each effect is determined by the severity of the impact, the spatial extent, the duration of the effect, and the potential involvement of commercial species.

To comply with EPA's interpretation of the Marine Pollution, Research, and Sanctuaries Act of 1972, ("Ocean Dumping Act") [13], an ocean disposal site for processed wastes must be designated and monitored to assure that "no adverse effects" result from dumping.

Four possible classes of ocean disposal sites exist for processed nodule tailings. These include (a) a near-shore outfall, (b) a near-shore dumpsite, (c) a continental shelf disposal site, and (d) a deep-ocean disposal site. In 1982, a study of potential tailings dumpsites along the Pacific coast and off Hawaii were evaluated for multiple environmental impacts based on biological and oceanographic characteristics [4]. Each site was ranked by productivity, fisheries potential, and dilution and dispersal potential (Tables 35 and 36). Physical and biological considerations rank deep ocean disposal as a feasible option. Therefore, the monitoring and surveying systems in this report are

Table 35. Evaluation of the Environmental Significance of Disposal Area Options Within Each Representative Disposal Area

	Nearshore Outfall	Nearshore Dump	Shelf	Deep Ocean
Pacific Northwest	4	3	2	1
South California	3	3	2	1
Hawaii	2	2	N/A	1
Western Gulf of Mexico	N/A		3	1

Note: Each disposal option is ranked from 1 to 4, with a rank of 4 representing the greatest environmental significance.

Source: Bigham, et al., 1982.

Table 36. Effects of Disposal Area on Factors Related to Potential Impacts of Waste Disposal

Disposal Area	Relative Deposition Rate	Relative Area Affected	Potential Dilution	Relative Organism Sensitivities	Recovery Potential	Trophic Link With Fisheries
Nearshore	High	Limited	Limited	Low	High	High
Shelf	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate to High
Deep Ocean	Low	Extensive	High	High	Low	Very Liimited

Source: Bigham, et al., 1982.

designed for a deep ocean disposal site.

The dilution potential of processed wastes is greatest in the deep ocean, thus, reducing the impact in one particular area. Biological productivity decreases seaward of the continental shelf in deeper water. Vertical stratification of the open ocean limits the upward flux of nutrients into the epipelagic zone, and, as a consequence, primary production is low. Figure 25 shows that primary organic matter production is 10 to 60 grams of carbon per square meter per day in nutrient-rich coastal waters, compared to less than 0.5 grams carbon per square meter per day in the open ocean [35]. Because primary productivity is small in surface waters and a deep water column separates the bottom benthic communities from the surface waters, very little food reaches the benthos, thus benthic populations are low. The average biomass of the deep-ocean benthos is no more than 0.01 percent of that of the coastal shelf. Pelagic life, including commercially important fishes, are markedly scarce in oceanic waters. The deep ocean fishery, composed mainly of tunas and billfish, forms less than 5 percent of the tonnage of the shelf slope bottom catch. In the United States, no demersal fishery exists deeper than the 1,000 meter isobath [37], largely due to the decrease in food availability with increasing depth. This information is important in selection of the disposal site in the deep-ocean.

Results of the DOMES project and other disposal studies ([4] and [37]) conclude that there will be short-term, transitory but harmless effects on the sparse biota in the deep sea. Table 37 summarizes the short-term effects of dredged material disposal in the deep and shallow oceans, which also was examined in selection of a deep water tailings dumpsite. Although the DOMES work has provided an estimate or assessment of effects of the mining ship discharge on the environment and its inhabitants, extrapolation of surface and

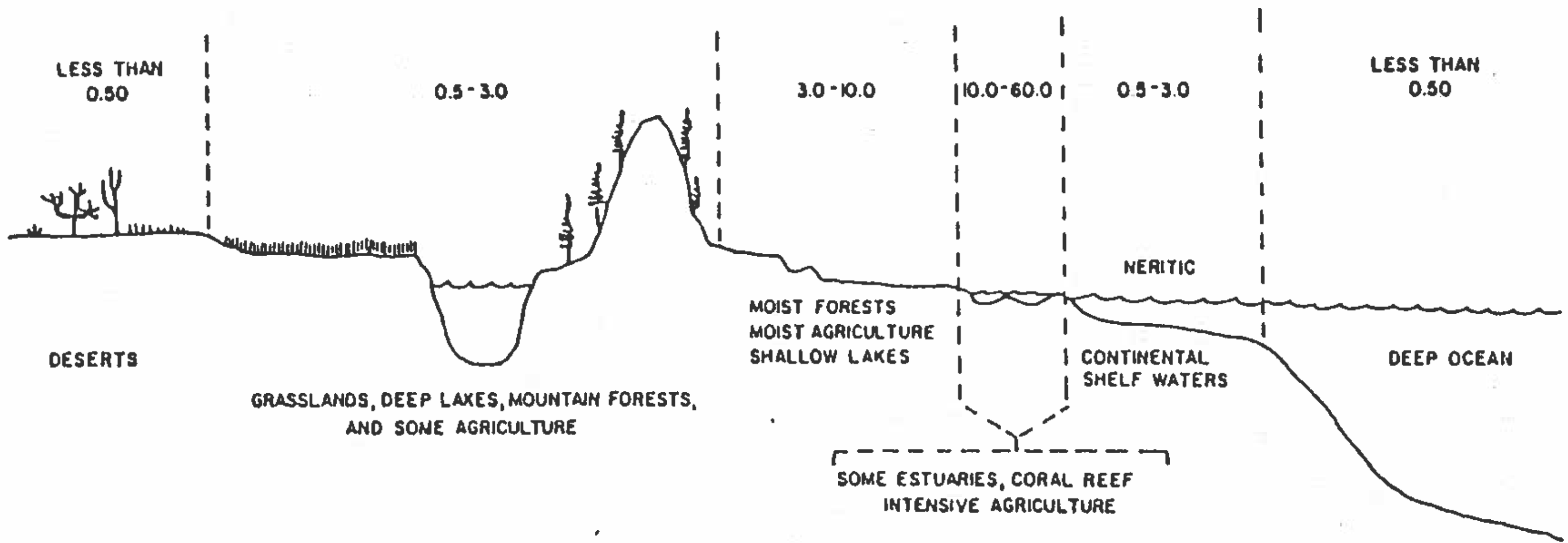


Figure 25. World Distribution of Primary Production. The units are grams of organic matter per m^2 per day (adapted from Odum, 1959).

Source: Pequegnat, 1978.

Table 37. Comparison of Short-Term Effects of Dredged Material Disposal Between Shallow Water and the Deep Ocean

Effect	Shallow Water	Deep Ocean
Turbidity		
1. Reduce light penetration	Can be important to phytoplankton and phytobenthos	Little photoplankton and no phytobenthos
	Can have effects on hermatypic corals	No reef building corals
2. Flocculate phytoplankton	Can be important in estuaries and above thermocline in neritic waters	Little effect
3. Aesthetically displeasing	Strong possibility	Little effect
4. Decrease availability of food	May be important	May increase food supplies
	Dilution of food particles with useless material	Carry organic matter (POC)
5. Drive mobile organisms out of an environment	Temporary effect	Animals adapted to nepheloid layer
6. Affect respiratory surfaces	Can be important	Dilution and dispersion reduces potential effect
7. Sorption of toxic materials	Can be important to filter-feeders	Widely dispersed, reduced number of filter feeders
Bottom Sediment Buildup		
1. Smother benthic organisms	Can be important because biomass high	Less important because biomass low
	High proportion of epibenthic species	Also higher proportion of infaunal species
2. Destroy spawning areas	May be important	Relative effects unknown
3. Reduce phytobenthos cover	Locally important to sea grass beds	No sea grass beds
4. Effect on bottom habitat diversity (change in grain-size distribution)	May reduce diversity	Probably will increase habitat diversity by introduction of coarse material

Table 37. Continued

Effect	Shallow Water	Deep Ocean
Depletion of Dissolved Oxygen		
1. Suffocate organisms	Important, but species specific	Anoxia not as severe a problem in deep sediments
2. Can cause release of materials	Important locally	Lower concentrations will occur in deep waters

Source: Pequegnat, 1978.

bottom sediment plume effects to processed wastes are not totally appropriate because the chemical composition of the processed nodule wastes and the mining discharge are different.

EPA Disposal Permits

Under the 1972 Marine Pollution, Research and Sanctuaries Act [13], disposal of any material into the marine environment requires an application and a permit. There are five categories of permits: (a) general permits are issued for dumping materials with minimal environmental impact and generally disposed of in small quantities, (b) emergency permits are needed for disposal of toxic and hazardous materials, (c) research permits may be issued if disposal of material is part of a research project, (d) special permits are for materials meeting EPA water quality criteria and are good for three years, (e) interim permits most likely will be issued by the Environmental Protection Agency (EPA) for the disposal of processed manganese nodule wastes, because the disposal may exceed the permissible criteria before dilution occurs.

The applicant submits to EPA the physical and chemical description of the waste material, the quantities of wastes involved, anticipated duration and method of disposal, the processes or activities giving rise to the production of the waste material, and a list of disposal alternatives and sites. With each application, an environmental assessment of potential and unavoidable environmental impacts of dumping at the nominated sites is required, as well as a thorough review of the need for disposal. The evaluation and decision of whether or not to grant an interim ocean disposal permit is based on the degree of treatment, if any, needed to meet EPA disposal standards, the relative environmental impact of continuous disposal, and the temporary or permanent effects on alternative uses of the oceans, such as navigation, exploitation of living and non-living resources, or scientific study. Waste can be dumped only if the material proposed meets the limiting permissible concentrations of total pollutants as defined in the Act, considering concentration, dilution and mixing processes.

After submission, EPA publishes a public notice of the application that is sent out to specific Federal, State, and local governmental agencies and the concerned public. If anyone requests a public hearing, the permit will not be issued until the hearing has been conducted. After full consideration of the cases presented, a Presiding Officer of the hearing recommends the issuance or denial of the permit. Permittees must collect complete records including the nature and description of relevant physical and chemical characteristics of the disposed material, the precise time and location of disposal, and any other information required as a condition of the permit. Periodic reports to EPA officials are mandatory, at least every six months and at the expiration of each interim permit. Interim permits expire after one year, but a new permit can be issued each year.

The size of ocean disposal sites will be limited in order to localize for identification and control any immediate adverse impacts, and permit the implementation of effective monitoring programs to prevent long-term impacts. The primary purpose of the monitoring program is to evaluate the impact of disposal on the marine environment by comparing the monitoring results to baseline conditions. The extent of impacts will be based on progressive, non-seasonal changes in water quality, sediment composition and in composition or numbers of pelagic, demersal or benthic biota at or near the disposal site when they are attributable to the disposed materials. Contingent on the results from the disposal site monitoring, EPA can modify or terminate the use of a disposal site, depending on the severity of environmental impacts. Amendments to the permit can permanently change the total specified quantities or types of wastes discharged at a site. Thus, prospective deep ocean mining venturers are not assured before GO for the construction period that ocean disposal of tailings and wastes will be permitted for the duration of commercial production.

Tailings Characteristics

To assess environmental impacts of deep ocean disposal of the processed material, the physical and chemical characteristics of the wastes and the nature of the disposal site must be known. Actual full-scale processing has not taken place. First-generation processing tests reveal that the nodule metals will be separated chemically or hydrometallurgically. The nodule constituents are returned to solution using either a hydrochloric acid leach, a sulfuric acid leach or a cuprion-ammoniacal leach [7]. Estimated rates of metals production indicated that a first-generation plant would process three million tonnes of solid wastes from a three-metal plant, or one-half to one million tonne per year from a four-metal plant [6]. Waste products from the leaching processes will be in slurry form and consist of finely divided tailings, fused salts, unrecovered metals, unrecovered reagents, slimes, wetting agents, lixes, and traces of other compounds. Further treatment may be required to stabilize the wastes to meet EPA dumping standards if they apply, or international standards. Based on the production estimates, two barge loads per week of 6,000 to 8,000 tonnes each are needed to handle the volume of wastes [12].

The chemical characteristics of the reject discharge were estimated [4] for the major and minor constituents and are shown in Table 38. The environmental impact of toxic metals in the rejects is determined by their availability to the marine environment. All metals are expected to be bonded in solid phase or complexed, with only a small percentage in ionic form. The

Table 38. Chemical Character of Rejects[a] and Percent of Original Input

	Element	R/A Leach	CUPRION/ Ammonia Leach	H_2SO_4 Leach	Smelting Matte Rejects	Smelting Granulated Slag
Major Constituents in Percent	MnII[b]	12.5[c] (50)	12.5 (50)	(50)	--	25 (100)
	MnIV	12.5 (50)	12.5 (50)	(50)	--	--
	Fe	8.5 (100)	8.5 (100)		--	8.5 (100)
	Al	2.7 (100)	2.7 (100)		ND[d]	ND
	Si	6.8 (100)	6.8 (100)		ND	ND
Potentially Toxic Constituents (ppm)	Ba	4,645 (100)	3,600 (100)	3,610 (100)	--	6,474 (100)
	La	1,680 (90)	1,400 (95)	744 (50)	--	2,669 (100)
	V	418 (90)	300 (80)	36 (10)	--	353 (50)
	Cr	10.5 (90)	8 (90)	8.1 (90)	--	8.7 (55)
	Ag	0.35 (10)	0.3 (10)	0.28 (10)	202 (50)	-- --
	Cd	2.3 (10)	2 (10)	--	12.8 (1)	14.6 (45)
	As	29 (50)	33 (70)	4.5 (10)	565 (10)	8 (10)
	Sb	31.4 (90)	25 (90)	2.7 (10)	390 (10)	--
	Tl	23.2 (10)	33 (20)	90 (50)	128 (1)	146 (45)
	Pb	523 (90)	411 (90)	409 (90)	2,906 (5)	368 (45)

[a] All values calculated from Dames and Moore (1977, Vol. III).

[b] Estimated worst case of unoxidized Mn.

[c] Upper value is concentration in rejects (in percent or ppm). Value in parentheses is the percentage of the original concentration in nodules present in the waste.

[d] ND = no data.

Source: Bigham et al, 1982.

pH of the wastes will be adjusted before discharge to between 6.5 and 8.0. The conclusion drawn from initial studies of manganese nodule waste disposal was that after initial dilution, the wastes will meet present EPA water quality criteria as listed in Table 39. Radioactivity, PCBs and other toxic elements are not produced during the processing.

The chemical and physical characteristics of the processed waste material will be very different from those of the bottom sediments. In the open ocean, the dissolved oxygen level determines the oxidation-reduction (redox) character of the environment. Due to the absence of organic material in the waste components, significant oxygen demand in the disposal area is unlikely. At a deep-water disposal site, the chemical properties are not expected to be significantly altered by waste because of the large dilution factor. However, the accumulation of the disposal tailings may change the local pH. Over time, trace metals may become detectable because adsorption-desorption reactions involving trace metals are controlled by specific, pH-dependent surface reactions in which metal ions are exchanged for surface-bound hydrogen ions. In general, metals adsorb with increasing pH and desorb with decreasing pH. Also, initial salinity changes in the disposal slurry will result in pH changes and metal availability and should be monitored.

Disposal Characteristics

Several intrinsic factors will determine the spatial distribution and physical fate of the manganese nodule waste material. The most important factors are the particle sizes at the time of and shortly after disposal, and the bulk density of the waste material. As the material is discharged, most of the wastes will be accelerated by gravity, reaching maximum speed in the first few meters. The sinking speed of the surface plume decreases with the entrainment of ambient seawater and will suffer dynamic, vertical collapse and

Table 39. Comparison of Dissolved Metals Concentrations to Water Quality Criteria for Marine Waters

	Nodule Processing Waste Dissolved Metals Concentrations[a] ug/l	EPA Water Quality Criteria, 24-h Avg. ug/l	Dilution Required for Outfall[b]	EPA Water Quality Criteria, Maximum ug/l	Dilution Required for Dumping[b]
As	25	no criterion	no criterion	508	0
Cd	<50	4.5	11:1	59	0
Cr	<100	18	6:1	1,260	0
Cu	<50	4	13:1	23	2:1
Hg	<0.3	0.025	12:1	3.7	0
Ni	<200	7.1	28:1	140	2:1
Pb	<10	25	0	668	0
Zn	<40	58	0	170	0

[a] Results are from one analysis of wastes from a CUPRION process pilot plant and are considered not to be representative of waste from a full-scale plant.

[b] Assumes concentration in waste equal to "<" value; e.g., <50 = 50.

Criteria values from Federal Register, November 28, 1980.

Source: Bigham, et al, 1982.

horizontal spreading upon encountering the strong pycnocline, prominent in the deep ocean, similar to that shown in Figure 26 [37]. The denser material falls through the pycnocline to the sea bottom, while the lighter fines enter a slow, long term dispersion and settlement phase. Settlement may be enhanced through ingestion and compaction of the fines into the fecal pellets of filter-feeding organisms such as copepods [19].

To estimate the extent of area covered by the disposal material in deep water is difficult. Both the pycnocline and currents have considerable effects, especially on the fine material. Two major potential causes of impacts are increased volumes of water containing SPM, and chemical reactions of waste materials producing toxic byproducts. Because the water column transit of the fine material would be long, dilution would be sufficiently great so that little or no irreversible effects upon pelagic life are anticipated [4].

On the bottom, accumulation of waste material from continual dumping has the potential of affecting the normal structure and function of the benthic community. Constant burial of the benthic fauna and its food supply, both of which are already sparse, will cause changes in species composition. Species that can dig strenuously and tolerate intermittent exposure to large quantities of particulate matter will replace weaker, less tolerant species.

Benthic organisms play an important role in both the distribution and chemical fate of the disposed material. Although deep-sea benthic invertebrates are predominantly deposit feeders, some are also suspension or filter feeders. There is a steady reworking and compaction of sediment through and around these organisms. Over time, potentially toxic elements and compounds in the sediment may be subject to conditions different from those in the overlying water column. Under those conditions, the potential toxins may

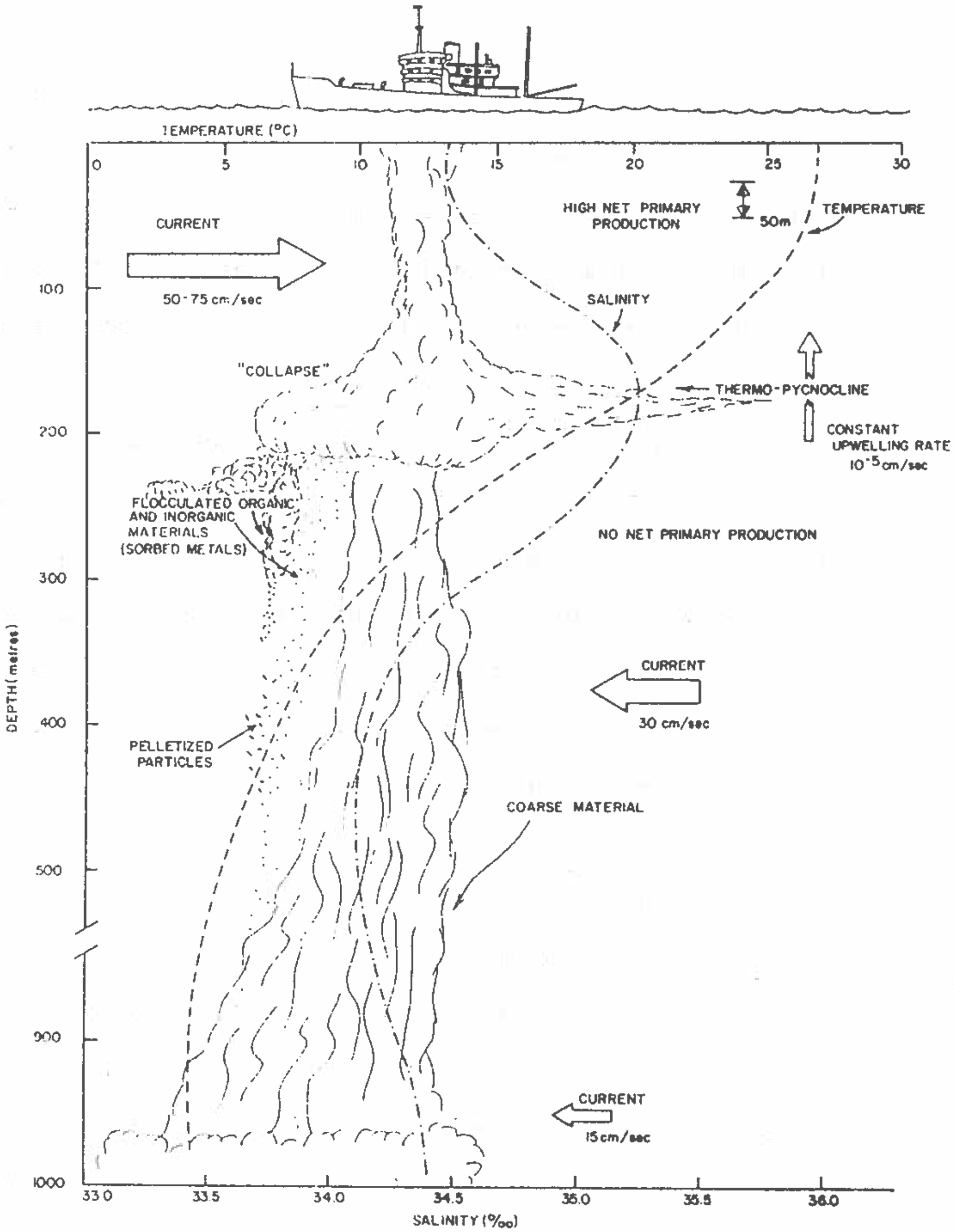


Figure 26. A schematic picture of the disposal of hopper-dredged material into a two-layered deepwater system (1000 m) with a strong thermo-pycnocline. Note the depth of high net primary production (25-50 m), the spreading of some fine material on the thermocline, and the minimal effect of upwelling as material passes through the thermocline.

Note: Numerical values not accurate for deep-sea sites.
Source: Pequegnat, 1978.

be released and made available to ingestion or absorption by the benthic community. Bioaccumulation of toxic materials by the benthos of toxic materials is one of the major unresolved concerns in the ocean dumping controversy and the main reasons that a monitoring system is required [3].

Infaunal invertebrates are particularly susceptible to substrate alteration because most species have well-defined habitat requirements associated with sediment grain size and organic material content. After waste disposal, organisms from the surrounding, undisturbed areas will begin recolonization. Opportunistic colonizers such as the family of deposit-feeding polychaete worms, Capitellidae, will most likely initiate the recovery process. Because deposit feeders ingest deposited sediment on and below the surface, members of the family Capitellidae would be a good indicator of community recovery [18] and potential bioaccumulation effects [36].

Description of Monitoring Equipment

The instrument monitoring system at the disposal site is similar to the one used at the mining site. The Interocean Data Acquisition Model 590 is again used. The instrument array includes a water sampler, current meter and data recorder, and a beam transmissometer for SPM. In addition, the instrument array at the dumpsite will measure dissolved oxygen, pH, redox potential, and concentration of trace metallic elements.

A voltaic polarographic membrane sensor, consisting of a platinum cathode and a silver anode in a solution of potassium chloride, will monitor dissolved oxygen. The sensor is not affected by changes in water flow rate. The dissolved oxygen monitor automatically compensates for temperature because a linearized thermistor output is used to adjust the gain of the signal-processing amplifier.

The pH sensor incorporates the reference electrode and the measuring electrode into one combination sensor and reports pH on the conventional scale of 1 to 14. Temperature compensation is automatic.

Oxidation-reduction (redox) is measured with a sensor that calculates the EMF difference between a metallic sensing electrode and a constant voltage reference electrode. Output in millivolts is amplified with high input impedance.

The Model 590 unit can measure concentrations of lead, cadmium, arsenic and copper ions. Sensors manufactured by Orion are adapted to the water environment and provide accurate measurements within one part per million.

Disposal Monitoring and Surveying

Waste disposal is a three dimensional problem in the ocean, hence the characteristics of the water column as well as the bottom are of interest in defining the disposal environment. In choosing a marine disposal site, location, ocean column hydrodynamics and biodynamics should be considered.

Before disposal of processed nodules from commercial operations, the Marine Pollution, Research and Sanctuaries Act requires that an EPA permit be obtained. Baseline chemical, geological, physical and biological characterizations of the site will be needed to supplement the permittee's EIS. Once the site and a monitoring program are approved during the time before GO, dumping of the processed wastes can begin in Year 7.

To aid in visualizing the monitoring and surveying systems set-up, a two kilometer, cylindrical, deep-water disposal site defines the area of release. Five sampling stations are shown at the periphery of the disposal site in Figure 27. Ten instrument array units are placed at the bottom, downstream in the expected current at the disposal site. A designated station upstream, which also contains an instrument array, acts as a control. Actual placement

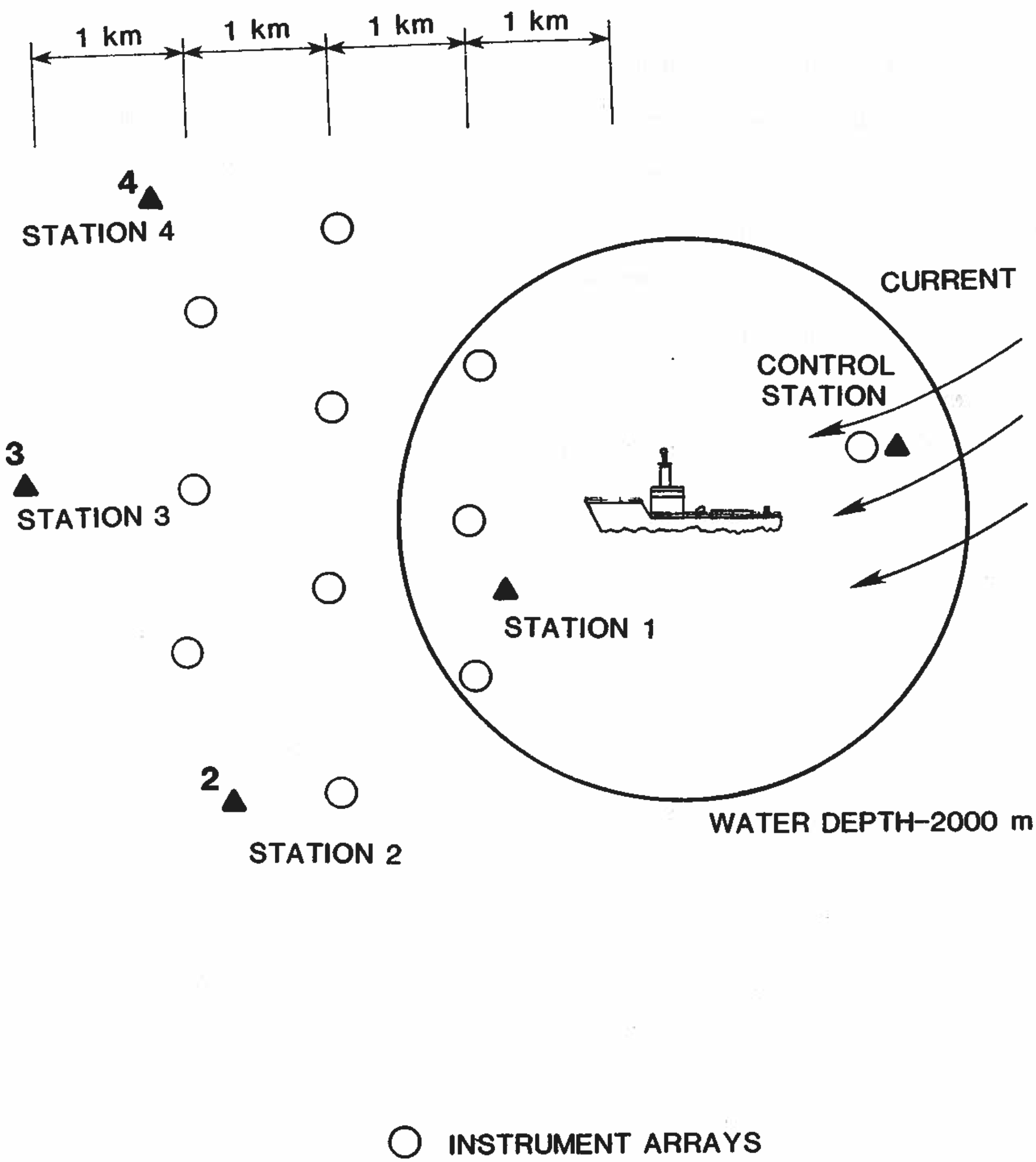


Figure 27. Hypothetical Disposal Site

of stations and instrument arrays depends on the location of the disposal site. More arrays and stations may have to be placed upstream if current reversals periodically occur. The number of survey stations may also vary depending on the spatial extent of the waste plume and the expected impact on the surrounding area.

Table 40 proposes a schedule for disposal site environmental inspection activities. The surveys are similar to the mine site surveys and could be incorporated in the same survey if the disposal site is along the route to the mining area. Full-scale surveys, as required in the permit, will begin probably in the test Year 6 and continue through the first three years of commercial dumping operations, Year 7 through Year 9. Surveys will be conducted biannually (more often if found necessary) and will include biological, chemical, geological and physical data collection as described in Table 41. If the accumulated data verifies conclusions drawn in the EIS and no adverse effects are apparent or anticipated from nodule waste disposal, fewer surveys may be approved during Years 10 through 17, with a possible additional reduction in the last years of mining to the end of dumping operations. However, if disposal does create a foreseeable impact on the environment, EPA will enforce measures to increase monitoring, or cease disposal operations until the problem is corrected.

Cost of Disposal Site Monitoring and Surveying

The dumpsite surveying costs are estimated on the assumption that a research vessel will be employed for a one-week voyage for each survey, twice a year, and the total crew effort will be about two weeks per voyage, to allow for travel and equipment servicing. Some expensive, specific equipment would be acquired for monitoring and surveying, for both the mining and disposal sites. The capital cost for box corers, trawls, television, photographic

Table 40. Disposal Site Monitoring and Surveying Program (Deep Sea Site)

Prior to Year 0, Probably 3 Years before GO	Baseline Study; prepare impact assessment and obtain disposal permits
Year 6	Set up instrument arrays
Year 7 thru Year 9	Five Sampling Sites - Full scale surveys (2 per year) (includes control site) after dumping starts
Year 9	Evaluate. Does sampled data correlate with array data? Yes - reduce surveys No - resume full-scale surveys
Year 10 thru Year 17	Reduced Surveys (1 or 2 per year) - to retrieve data and maintain arrays - collect biological data - collect chemical data
Year 17 thru End of dumping	Reduced Surveys (1 per year) - maintain arrays and collect data - collect biological sampling - collect chemical sampling

* Full and reduced surveys same as surveys in mining site.

Table 41. Survey Contents at Deep Ocean Disposal Sites

Full-Scale Surveys* (biannually)

Physical Measurements - at bottom depth and surface

	Item	Equipment
1	Current measurements	Current meters
2	Salinity with depth	CSTD
3	Temperature with depth	CSTD
4	Meteorological data	Standard shipboard
5	pH	Water bottle samples
6	Redox	Water bottle samples
7	Dissolved oxygen	Water bottle samples

Geological Measurements - at bottom

1	Particulate suspension	Beam transmissiometer

Chemical Measurements - at bottom and surface

1	Trace metals, toxic elements, and heavy metals in water column	Water bottle, atomic absorption spectrophotometer
2	Trace metals, toxic elements, and heavy metals in sediments	Box corer, atomic absorption, spectrophotometer
3	Dissolved nutrients	Autoanalyzer, water bottle samples

Biological Measurements - at bottom and surface

1	Fish effects	Midwater trawl or purse seine
2	Larvae and plankton effects	Bongo and neuston
3	Benthic effects	Box corer (0.25 square meter)

* Annual instrument array data pick-up and maintenance also will take place on surveys.

Table 41. Concluded

Item	Equipment
Reduced Surveys* (biannually initially, reduced to annual surveys)	
Biological Measurements - at bottom and surface	
1 Fish effects	Midwater trawl
2 Larvae and plankton effects	Bongo and neuston
3 Benthic effects	Box corer
Chemical Measurements - at bottom	
1 Trace metals, heavy metals and toxic elements in water column	Water bottle, atomic absorption spectrophotometer
2 Trace metals, heavy metals and toxic elements in sediment	Box corer, atomic absorption spectrophotometer
3 Dissolved nutrients	Autoanalyzer, water bottle samples
Physical Measurements	
1 Meteorological data	Standard Shipboard

* Annual instrument array data pick-up and maintenance also will take place on surveys.

equipment, spectophotometer, etc., in conjunction with mining site monitoring equipment, would be comparatively small, and so the $1.6 million instrument array capital costs were increased by $200,000.

The annual survey operations would require replacement of anchors, acoustic beacons and lost equipment, charter of a 150-foot research vessel; specimen and data storage; analysis equipment; laboratory analysis and reports; reports to the government; and maintenance. Total operating costs should not exceed one-half million dollars per year per voyage, for two survey trips to five sites each, and eleven instrument arrays each recovered and replaced per voyage. The total costs of the on-land laboratory would be about a million dollars annually, bringing total operating costs to 1982 $3 million (See Table 42).

Table 42. Deep-Sea Disposal Site Monitoring Instrument Costs

Unit	Unit Cost	Number	Total Cost
Buoyancy	2,000	44	$ 88,000
O_2, pH, Redox, 4 metals and recorder	40,000	22	880,000
Current Meter	11,700	22	257,400
Acoustic Release	8,000	44	352,000
Water Sampler	500	22	11,000
Hardware	200	22	4,400
Anchors	100	22	2,200
	INSTRUMENT ARRAY COST		$1,595,000

Total Costs

The total monitoring and surveying program for both mining and deep-ocean disposal sites, as described in this section could be accomplished by one or two research vessels, depending upon survey timing, site locations and other activities of the exploration-research vessel. Total annual capital costs of $5 million dollars in 1982, and operating costs of $3 million are estimated.

These costs were added to Sector 8 and the payout periods and rate of return computed. By comparison to the base case described in Section III, the IROR after tax decreased by 0.13 percent. This level of change of return in Discounted Cash Flow basis is barely perceptible and indicates that the environmental monitoring proposed here does not significantly affect the costs or returns of the pioneer venture.

V

CONCLUSIONS

Base Case

For a gross investment of $1.43 billion in a base-case four-metal plant costing $870 million in 1982, a plant with an annual throughput of 1.5 million dry short tons of nodules can be constructed. With output of manganese, nickel, copper and cobalt, plus minimal other products, net annual sales of $525 million at the assumed metal prices can be obtained. The simple annual average profits are $183 million before taxes and $136 million after taxes, with standard federal tax treatment using the new five-year plant depreciation, ten percent investment tax credit, and 15-year carry-forwards. The back periods are more than 14 years for the total investment and 11 years for the fixed investment only. Using the discounted cash flow analysis, the before tax internal rate of return is 8.6 percent, and 6.4 percent after taxes.

Considering the degree of risk involved, this four-metal low throughput mining system is not an attractive investment candidate under the base-case conditions. Government securities with low risk have had yields about double these returns, and even future rates of treasury issues are presently predicted at higher interest levels. The cost of money is not expected to decrease to less than about 10 percent for the short-term future, and returns of three to four times the cost of money are demanded for high-risk ventures.

Alternate Locations

The Pacific Northwest alternate location for the four-metal processing plants was evaluated using only identifiable extra costs for transportation and neglecting any possible savings over the southern California plant site. Because of the very low power cost, three cents vs. 11 cents per kilowatt-hour, this alternative shows a 9.8 percent after-tax internal rate of return, almost the best computed under any situation without stretching the credibility of the base-case assumptions. This alternative is feasible, using coal for minimum power co-generation, and can also benefit from all of the refinements which apply to the southern California base case. Further, accelerated construction is deemed more likely in Washington or Oregon than in California.

Alternate Plants

The ammoniacal leach, three-metal plant analyzed in [17] as updated in cost to 1982 levels and the Payout Program used with the same unit sales prices as in 1980. This larger plant (of 3 million short dry tons of annual nodule throughput) is even less attractive after two years of inflation, yielding only four percent discounted, after-tax internal rate of return.

However, the addition of a tailings-processing plant for manganese recovery increases the revenues, by $675 million. At expected levels of investment and operating cost, the profit increases from $144 million before and $123 million after taxes, to $441 and $327 million, respectively. Thus, yields of 16.4 percent before and 12.4 percent after tax

IROR are produced. These better results were based on a southern California location and electricity costing 11 cents per kilowatt-hour. The improvement of about 6.5 percent in IROR over the three-metal base case in part reflects the economies of scale of the three million tons per year three-metal case over the 1.5 million tons per year for the base four-metal case. The principal conclusion of this analysis is that manganese production is essential for project returns to become attractive. The ability of the market to absorb the manganese produced at this price is assumed.

The cost was computed for a three-metal plant with tailings processed for manganese with a power cost of three cents per kilowatt-hour in the Pacific Northwest, including the increased transport cost. The saving of $140 million annually in operating cost provides the basis for increasing the IROR to 20.3 percent before and 15.4 percent after tax (Table 43), the best results produced in this project.

Sensitivity Analyses

The series of capital and operating cost sector changes, and computations of returns, illustrated that operating cost containment is more important than capital cost controls at these low rates of return. Further, the high-risk ocean mining sector is not nearly the most significant cost element, and extra money invested in ocean mining to assure performance probably will benefit the whole project. Transportation and waste disposal costs are relatively small and not likely to vary significantly. The significant cost element is in the processing sector, three-quarters of all the monetary benefits may be secured from design improvements over the base case. Of these base-case processing operating costs, almost half are for power, and a quarter are for fuels and water. Therefore, power and fuel efficiency and economy are the prime targets for system improvements. The two processes examined here are adaptations of existing technology for manganese nodules and were not developed to suit the unique nodule characteristics.

Other areas for increased profitability include the use of chartered foreign transport and mining ships; accelerated construction of the facilities; reduction of the effective profits tax rate through depletion or other special treatment; low-cost or free-debt financing; free prospecting, exploration and R&D funding to minimize front-end costs; and high prices for the metals -- manganese and nickel in particular. The prior report [17] also identified desirable (although not large) improvements from location of the processing plant in the port and the possible payout losses due to small plant size, because of a lack of the economies of scale.

In the following table, these factors are numerically "rated" on the basis of improvement, relative to the base case, of the after-tax internal rate of return.

Change	Increase of IROR' (%)
Three-metal plant with tailings processed	+6.0
3¢/kw-hr power (Pacific Northwest) (minimum coal cogeneration)	3.5
75% of fixed plant-debt (zero interest rate)	2.8
Zero effective tax rate	2.6
No preparatory period expenses	1.7
Foreign ship charters	0.5
Accelerated construction	0.5
Process plant in port	0.3

An optimal case has been constructed that applies to a Pacific Northwest, three-metal manganese plant located in a port, using foreign-built and manned transport and miner ships, built under a four-year accelerated schedule. In addition for this optimal case, and most importantly, there are no governmental taxes; interest-free loans are available for over half of one billion dollars, and pays for all preparatory R&D.

Table 43 summarizes the results of this optimal combination. With complete governmental assistance, the three-metal plus manganese plant case, which has low electrical power use, in the Pacific Northwest location could turn a sizable profit that would be very attractive, even if not likely.

More realistically, less governmental support involving only R&D funding, an incentive tax rate equivalent to depletion allowance, and low-cost financing of the fixed plant at government-guaranteed debt interest rates would meet the current requirements of investors, in combination with all those decisions that possibly could be controlled by the pioneer venture, such as using foreign transport and miner ships, accelerated construction, and moving the process plant to the port where power is inexpensive. Thus, the ability of the government to expedite manganese nodule processing by a variety of actions is demonstrated, and should indicate that an "all of the above" approach is desirable for this objective.

Table 43. Best Combinations Producing High Returns - Reduction/Ammoniacal Leach Plus Smelter, Four Metal Plants, 3 million Short Dry Tons Per Annum, in the Pacific Northwest

	Pacific Northwest	OPTIMAL* PNW 31% Tax 10% Interest	OPTIMAL* PNW 0 Tax 0 Interest
Total Investment Equity	2,062.7	706.4	681.4
Fixed Capital Investment	1,369.7	1,153.5	1,153.5
Net Annual Revenue	1,069.9	1,069.9	1,069.9
Annual Operating Costs	428.4	412.0	412.0
S.L. Depreciation Expense	258.7	218.1	218.1
Preparatory Expenditures	195.0	0	0
Before Taxes			
Average Profit	630.8	546.9	604.0
Return on Equity Investment	31.50	77.43	88.64
Return on Fixed Capital	46.06	47.42	52.36
Payback on Equity Investment	9-5	5-9	5-5
Payback on Fixed Investment	8-5	6-7	6-2
Internal Rate of Return on Equity	20.33	37.59	42.28
After Taxes			
Average Profit	400.2	401.2	616.9
Return on Equity Investment	19.99	56.80	90.54
Return on Fixed Capital	29.22	34.79	53.48
Payback on Equity Investment	10-0	5-9	5-5
Payback on Fixed Capital	8-8	6-10	6-2
Internal Rate of Return on Equity	15.39	33.47	42.29

*Foreign ships, four year construction period, 75% of fixed plant, 20 year debt, no preparatory expenditures, 3¢/kw-hr.

Note: Dollar amounts in millions of 1982 U.S. dollars.
Returns as annual percentage.
Payback periods in years and months.

Recommendations

The above estimates or project payout do not constitute all new knowledge or provide specific insight as to appropriate steps to establish a successful deep ocean mining venture. However, these payout model results, and the prior analyses indicated (in the approximate order of payoff) the following areas for further analysis.

1. Selection and development of new nodule processes that include manganese recovery, as well as recovery of the other metals in their most profitable forms, in order to reduce the large plant capital and operating costs.
2. Development of metal recovery techniques that minimize use of electric power and can use coal as a primary energy source for co-generated power at the plant site.
3. Substantial governmental financial assistance, in the form of no-interest construction loans and funding of pioneering research and development, and assurance of percentage depletion allowance to reduce the income tax burden. Together, these supports have greater impact on the system profitability than all the other factors that are controllable by the pioneer mining and processing company. Any federal assistance, particularly at the start up, would be very beneficial in improving the attractiveness to investors. This would include allowing prospective ocean miners to develop jointly the necessary systems.
4. Use of foreign-built and manned transport and mining ships or financial provisions to provide cost parity. At present prices,

American ships and crews are removed from competitiveness in the international markets.

5. Acceleration of the plant and equipment construction period to reduce the investment period and carrying costs.
6. Location of the process plant at the nearest port, and use of nearby inland disposal sites, which would provide some small benefits [17].

Other factors are not controllable by the pioneer ventures and therefore even the most important of those listed below cannot be considered as a sure means to enhance the payout of the commercial ocean miner.

A. Higher prices for the metals produced are caused by economic demand, the cost increases of the major metal producers, or sometimes price coordination by the relatively few producers of these metals.

B. Government support for the industry is also an unknown and basically uncontrollable, but important, factor. Lacking direct financial assistance, the indirect support of R&D, or approved joint ventures, and maximum use of the tax code benefits, should be encouraged.

C. Environmental issues appear to be insignificant handicaps to rapid implementation of deep ocean mining systems, unless the permit and approval process is extended beyond the shortest term. No environmental harm is caused during the short term in the near field by the mining and disposal system, and the expected long-term impacts (to be monitored) are expected to be minimal. Efforts must be made to ensure that this situation is permanent and that rapid, permanent approvals are received.

Continuing Effort

The authors of this report have identified the list of areas deserving further analysis based on the above findings and recommendations. Several research projects are underway, supported by NOAA and the Department of Interior, that will be useful and can be incorporated in the proposed continuing project. These include examining alternative nodule processing technology, waste disposal, monitoring environmental impacts, and reviewing taxation to encourage private investment, as well as procedures to reduce paperwork, delays, costs, time, and amplification of requirements that accompany requests for the myriad permits required of any smokestack industry.

Proposed subjects of further analyses include:

1. Examine the forms of metal products used in industry, their market prices, different processes for their production and recovery rates, and the changes to capital and operating costs for selected process options. Investigate the likely cost increases of manganese products from other sources, which are expected to parallel those of ocean mining because of increasing energy, transportation and mining costs, and political considerations.
2. Prepare a scenario and define a mining, transportation, processing and waste disposal system for five to ten million dry tons per year of manganese nodules yielding four products: manganese, nickel, copper and cobalt, under optimal U.S. conditions and location. This would maximize the economies of scale, although market and antitrust considerations would become important. Estimate the

capital and operating costs of the system in 1983 U.S. dollars, and modify the Texas A&M University payout model to permit analysis of returns from this very high-volume, four-product system under the most recent tax laws.

3. Estimate the cost of a four-metal plant in a foreign country to process Pacific Ocean nodules. With relatively low power cost, or in a semi-developed location where construction and transportation cost considerations will be relatively favorable, or where cost of necessary infrastructure could be broadly estimated, proper, very site-specific estimates could be made.

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