TOWARD DEEP OCEAN MINING IN THE NINETIES

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

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RELATED SEA GRANT REPORTS

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

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

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I. Introduction and Overview

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

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

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

A. Pre-Production Phase

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

B. Contract and Construction (Investment) Phase

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

C. Commercial Operations

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

There are at least eight basic interdependent operations involved in the commercial operations phase of a deep ocean mining project. They are: 1) continuing R&D and exploration activities; 2) the mining operation and its supporting activities; 3) the transportation of ore from the minesite to the port terminal; 4) the operation of the ore discharge terminal; 5) the crew and supply vessel operation; 6) on-shore transportation to and from both the processing plant and the ore discharge terminal; 7) the nodule processing activities; and 8) the waste disposal operations. The activities, facilities and equipment assumed to be required for successfully conducting these commercial operations of an ongoing ocean mining project are outlined in more detail in section II-C. They are summarized here.

1. Continuing Research and Development and Continuing Exploration

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

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

2. Mining

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

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

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

7. Processing

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

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

8. Waste Disposal

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

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

II. Detailed Description of Events

A. Pre-Production Phase

Each consortium participant which considers ocean mining as a feasible project will probably have a "Long Range Planning" capability in the form of a company officer, a committee of the Board of Directors or a consultant to the Chairman of the Board and/or the Chief Executive Officer. It is the function of this capability to decide how, if at all, the project will proceed and to allocate funds for the prospecting and exploration (P&E) and research and development (R&D) efforts. Both the R&D and P&E efforts are divided into successive steps, each of which is funded based on the results of the previous steps. These intermittent "go/no-go" decisions (referred to a "G01", "G02", etc.) can be considered as "off-ramps" which are encountered at the end of one step and prior to the funding and commencement of the next. If the project evaluation conducted upon completion of one stage proves the project worthy of further investigation, the planning entity then allocates funding, probably at an increased level, for the next stage of work. If the project does not appear favorable, the decision to take the off-ramp could be made, thus resulting in shelving (a delay) or termination of the project. The P&E and R&D work conducted during the "up front" phase of the project establishes a bank of knowledge upon which the consortium entity will base the ultimate decision to go, or not to go, into the investment phase, and hence into commercial production. This ultimate decision will be referred to in this text as the final "go/no-go" decision. For this analysis, the project is assumed to pass the tests of technical success and economic viability at each decision point.

1. Pre-Commercial-Mining Prospecting and Exploration

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

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

a) Background Work

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

b) Prospecting

In prospecting, the aim is to identify potential minesites of commercial quality. First, a rough grid search of a large area is made. As an illustration, one firm's experience suggests that an area of approximately 400,000 square nautical miles be sampled, using free-fall grabs and still photographs.[1] Next, a medium grid search is made, further narrowing the sections for future surveying. Here, the above experience suggests an area of approximately 126,000 square nautical miles is sampled using free-fall grabs and still photographs, with the possibility of using a dredge to collect bulk samples on promising sections. Finally, a fine grid search is made to determine the area to be investigated during the exploration stages. An area of approximately 27,000 square nautical miles is sampled with free-fall grabs, still photos, a dredge allowing bulk samples to be used for chemical analysis, and spade or box cores. These activities can be completed in as few as two years.[2]

c) Exploration

The objects of exploration are to delineate the ore deposits, determine concentration and abundance of nodules, obtain soil mechanics data and map the potential minesite selected through the prospecting process. The selected area is searched with photographs and seismic surveys. Extensive sampling and bathymetric measurements are taken. As an illustration, an area of approximately 8,000 square nautical miles is surveyed, utilizing free-fall grabs, still photos, a dredge for bulk samples, spade and/or box cores. Bathymetric and seismic measurements are also made.

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

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

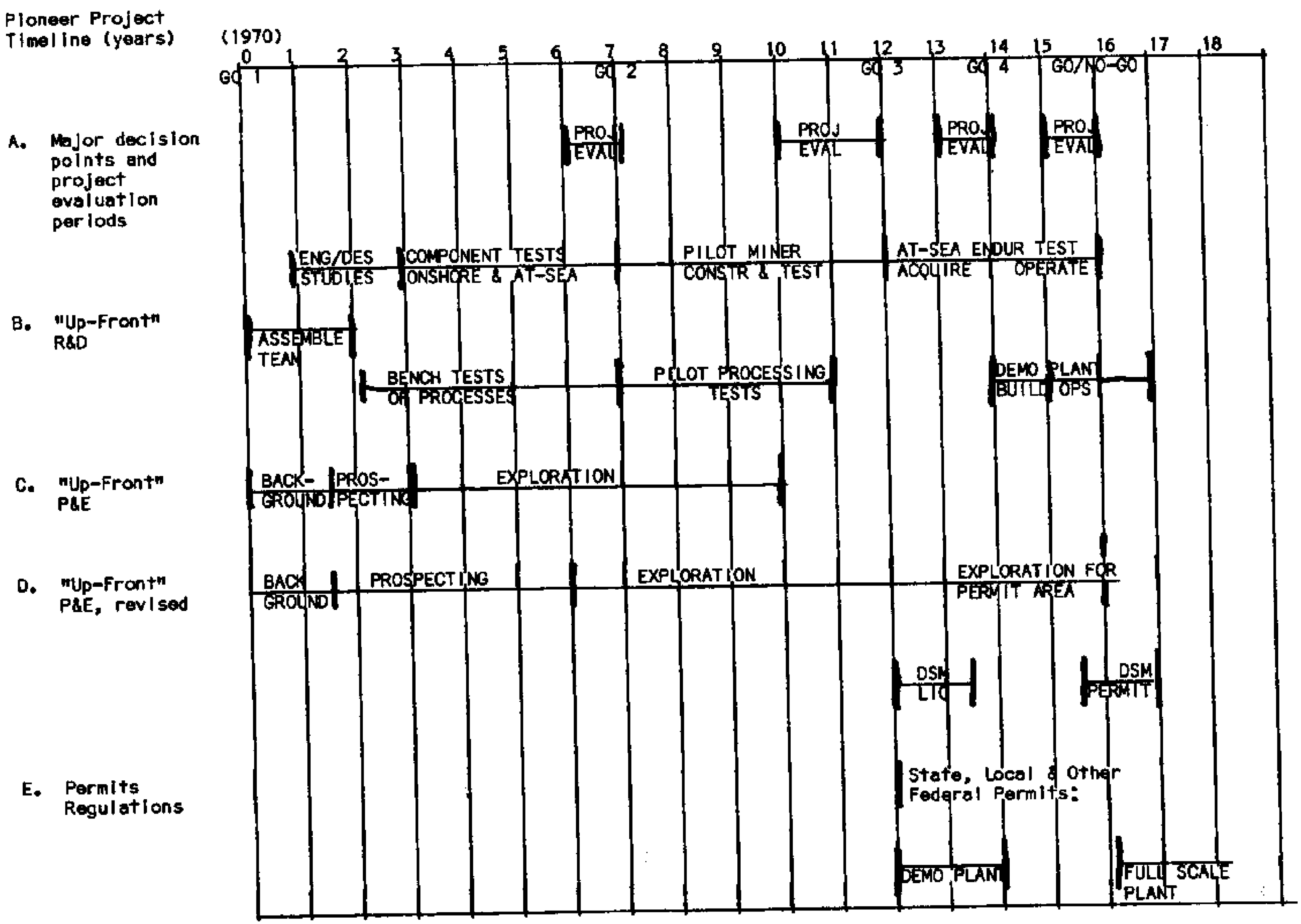
It has been estimated that these activities require approximately seven years if carried out without delay.

d) Timing of Prospecting and Exploration Stages

In this paper, the chronology of the events described above are assumed to begin in about 1970, with the one year's background work. This date approximates a representative beginning time of the four U.S. based consortia. The pre-commercial-mining events shown in Figures 1-B, 1-C and 1-D depict the P&E (as well as R&D) activities since then, with year 11 representing the situation at the time of writing, i.e., 1981. The consortia are approaching the end of their pre-commercial-mining phases, with critical

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

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



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

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

2. Pre-Commercial-Mining Research and Development

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

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

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

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

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

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

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

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

a) Timing

The beginning of the initial pre-mining R&D step is signified by the first "go" decision (GO1) as shown in Figure 1. This "go" decision results in the allocation of funds for the preliminary R&D work. As in the case of

P&E, this work is assumed to have started during 1970, the initial year of the project. This initial effort is conducted at low levels over a seven-year period (see Figures 1-A and 1-B). Following this period, and assuming some technical success, a second "go" decision is made in year 7. One consideration during the evaluation period preceding this "go" decision may be the need to secure additional financial participants in the venture. This "go" decision signals the beginning of major R&D activities for the project.

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

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

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

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

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

Halfway through this period, at the beginning of year 16 (or 1986), the decision of whether or not to invest in a commercial size project is made. This decision is based on all of the information gathered up until that time, with special emphasis on the results of the demonstration plant runs and mining system tests. This decision is referred to as the final "go/no-go" decision (see project timeline, Figure 1). The extra year of demonstration plant operation, after the final "go", is used to provide additional data for use in the design and operation of the full-scale plant.

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

It is assumed that the hypothetical operating entity is United States based and therefore subject to the U.S. Deep Seabed Hard Minerals Resource Act (P.L. 96-283), which regulates the conditions under which United States based entities must operate when mining the deep seabed. The Act requires that a U.S. deep ocean miner obtain a Deep Sea Mining (DSM) license before exploration and a Deep Sea Mining Permit before commercial recovery. Existing, i.e., pioneer, consortia are exempt from the prohibition against exploration before receiving a license, so long as they make timely application. Because U.S. interim legislation was enacted only in mid-1980, license applications of the existing consortia are not expected to be submitted until early 1982, or year 12 in Figure 1-E. The DSM license and permit processing periods will require one and a half and two years, respectively. (Both periods will run concurrently with R&D and P&E activities.) The license will thus be issued in mid-year 13. Halfway through year 15 (1985), application will be made for a DSM permit. The consortium should therefore have a DSM permit one year after the "go/no-go" decision.

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

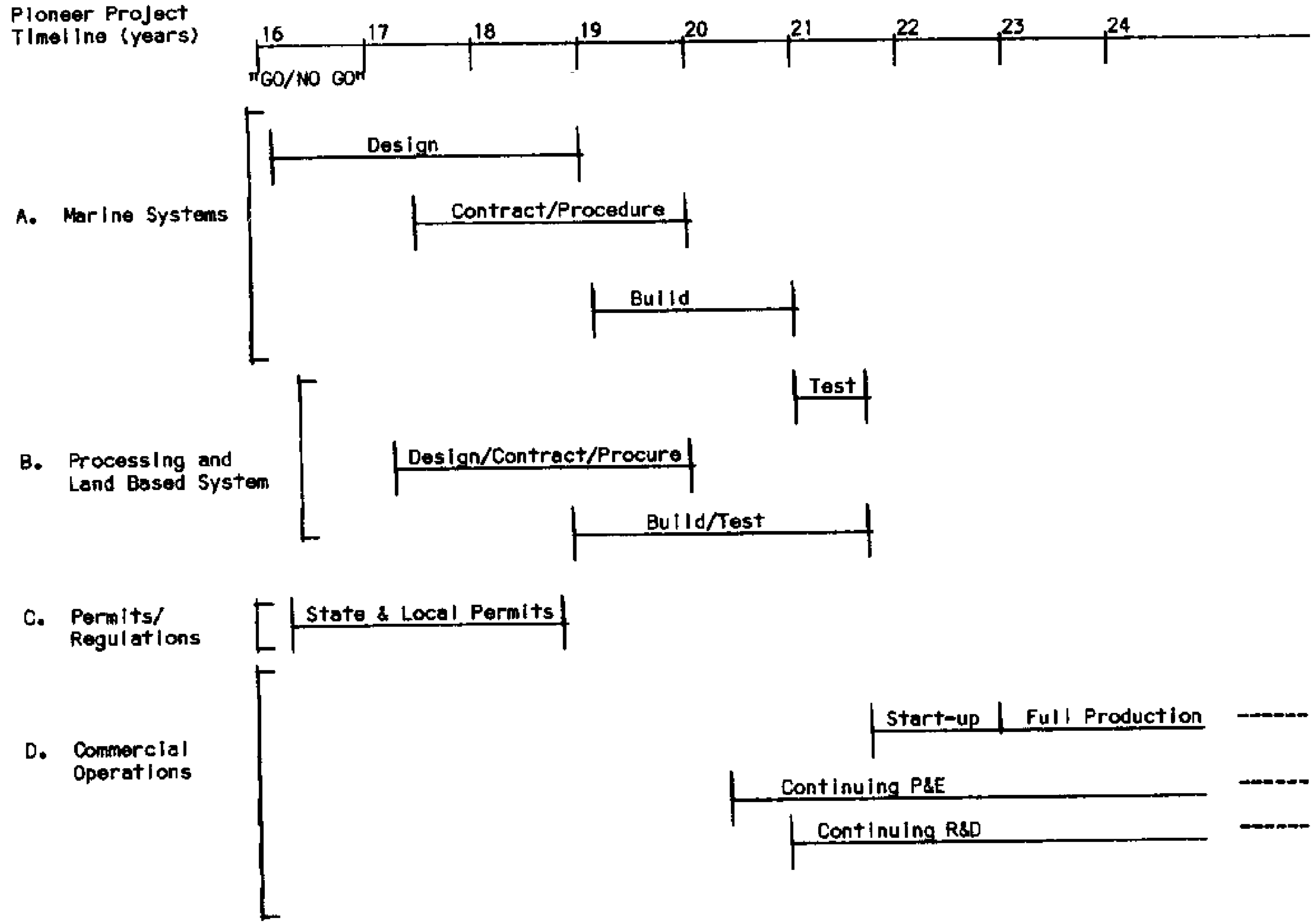
During the second stage of R&D, prior to the "go" decision for commitment to a fully commercial project, the type, size and quantity of equipment required for the project will be identified and design specifications developed. This work will include the preparation of contract plans and specifications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

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

Figure 2 A, B, C, D:

Timing of "Contract and Construction

and "Commercial Operations" Phases



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

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

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

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

The timing of these allocations may vary from sector to sector. Figure 2 gives an indication of the length of the contract and construction phase of the project for a pioneer venture. In addition, Figure 2 shows a breakdown of the contract and construction phase into time periods for both the marine systems (mineships and transport vessels) and for the land based facilities (processing plant, pipelines, port facilities and waste site).

From Figure 2, it can be seen that the mining system and transport vessel's contract and construction phase is assumed to require approximately five and one half years. The first years of this phase are assumed to be dedicated to the final design and permitting efforts, with the exception of the contract and procurement of the long lead-time components of the marine system (ships, dredge pipe, collector) which is taken to start one year and six months into this phase, during year 17 (1987) of the project timeline. This final design effort continues through year 18 (1988) of the project timeline, with extensions into year 19 (1989) for the dredge pipeline and collector systems. The contract and procurement activities, with the exception of those mentioned above, begin in year 17 of this phase and proceed through the end of year 19. Much of the actual building begins two and one half years into this phase and continues through the end of year 20 (1990). A six-month testing period is begun at the outset of year 21 of the project timeline. The purpose of this testing period is to allow for correcting deficiencies in the various systems, commissioning the vessels, and breaking in the equipment and personnel prior to the start-up operations.

The contract and construction phases for the commercial processing plant begins a year after the "go/no-go" decision and finishes four and one half years later in synchronization with the marine systems contract and construction phase. The detailed design effort and the contract and procurement activities start immediately with the onset of the processing plant contract and construction phase. These activities are scheduled at varying intensities through the first three to three and one half years of this phase. The actual construction begins two years into this same phase and is completed two and one half years later at the end of the contract and construction phase. It should also be noted that the land transportation items (slurry pipelines, rail spurs, roads), the port facility and the waste disposal site can be considered to follow a contract and construction phase schedule similar to that described above and for the processing plant. (See Figure 2.)

C. Commercial Production

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

1. Continuing R & D and Prospecting and Exploration

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

-- complete the topographic mapping of the year's mining area;

-- complete development of the mining plan at a pace one to two years ahead of the miner; and,

-- prospect for future minesites.

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

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

2. Mining

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

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

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

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

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

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

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

The dredge pipeline system will require the following items. The individual pipe sections of the lift (dredge) pipestring, whose length can be selected based on the ship and pipe suspension tower configuration, with larger lengths resulting in savings in coupling units and deployment time. Additional pieces of equipment for this system include pipe coupling units, deadweights for tensioning the pipestring, and pipeline fairing, if warranted, to reduce the dynamic effects on the pipestring. Due to the endless number of possible collector unit designs, no one unit is described.

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

The ore handling equipment should have provisions for four items: equipment for interfacing the mineship and the pipestring, thus allowing for the transfer of nodules between the two units; a separate unit for dewatering the nodules slurry when it reaches the surface; a slurry system or conveyors for moving the nodules to the stowage holds on the mineship; and finally, a slurry self-unloading system for transferring the nodules from the mineship holds to the transport vessels.

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

A special navigation system must also be developed to allow the miner to follow a pre-determined mining path. This system will most likely include electronic navigation equipment for position finding, bow and stern thrusters for position keeping and an electro-mechanical servo-control system for interfacing the electronics and the propulsion and ship control equipment.

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

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

3. Marine Transport

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

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

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

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

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

4. Ore Discharge Terminal

An ore discharge terminal facility will be developed in a deepwater port assumed for illustrative purposes to be on the West Coast of the United States. This facility will serve as the base for off-loading the ore from the transport vessels and preparing it for piping to the process plant. Additionally, at this facility the fuel and water supplies for the miner will be loaded onto the ore carriers for the return trip to the miner. Also, if the ocean dumping of process tailings is required, the vessels which dump the wastes (ore carriers and barges) will be loaded at this facility.

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

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

A pier and adjacent dolphins must be provided for mooring the ore ships. Probably only one dock facility will be necessary. However, if there is any significant overlap in port time for the various transport vessels due to the number of ore carriers and their respective schedules, an analysis must be made to determine whether it is more practical, from a financial standpoint, to build a new dock facility or to slow down the transport vessels, thus resulting in some increase in size and/or number of required vessels. The pier must be strong enough to support several moveable cranes mounted on a rail system (one for each hold of the transport vessel). These cranes will suspend the portable slurry discharge units to unload the ore transport vessels. The berth for these vessels must provide a water depth larger than the loaded draft of the vessels. This depth will be provided by dredging if necessary. In addition, if an access channel to connect the berth with the main channel is required, more dredging must be undertaken.

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

The terminal facility could have provisions for bunkering the ore transport vessel. The gear could include either one or more pipelines from a remote source in the port or on-premise tankage. In both cases, however, additional piping and pumps will be required to load the transport vessel.

An alternate method of bunkering could be via a bunkering barge which ties up to the transport vessel and fuels it from there. For this analysis, the ore carriers, as well as the mineships, are assumed to be powered by diesel engines; thus both vessels require diesel fuel.

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

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

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

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

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

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

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

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

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

a. Port to Process Plant Slurry Pipeline

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

b) Waste Slurry Pipeline

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

c) Roads and Railways

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

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

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

7. Processing

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

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

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

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

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

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

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

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

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

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

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

8. Waste Disposal Site Considerations

The disposal of processwastes, by slurry ponds, will require the use of a waste slurry pipeline system. The disposal of the slurred tailings will be assumed to be in impermeable slurry tailings ponds. These tailings ponds will be constructed at a waste site located as close to the processing plant as economically and environmentally possible. The distance from the plant to the waste site will probably be less than 100 miles.

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

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

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

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

III. Summary

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

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

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

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

If the final "go/no-go" decision is favorable, the project will enter the Investment and Construction phase in year 16. The design, contract and/or procure, build and test periods for the at-sea components of the project will require five and one half years as explained in section II-B.

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

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

NOTES

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

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

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