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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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DEEP SEABED MINERALS - MINING AND RELATED TECHNOLOGY: A STATUS REPORT

Summary**

Prepared by
the UNIDO Secretariat

* Organized by UNIDO in cooperation with the Government of India.
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MARINE INDUSTRIAL
TECHNOLOGY PROGRAMME

NEW TECHNOLOGIES UNIT, TECHNOLOGY DEVELOPMENT AND PROMOTION DIVISION

UNIDO, P.O.Box 300, A-1400 Vienna, Austria. Tel: (43-1)21131-5397/5030, Fax: (43-1)230-7355, Telex: 135612

PREFACE

This document is based on a report from a study made by a UNIDO Group of Experts[1] that during November 1991 visited a number of leading companies and institutions in Germany, Finland, Norway, France, U.S.A. and Japan dealing with ocean mining or related fields.

The study was commisioned under the UNIDO project US/GLO/91/200 with the objectives of: (a) prepare a status report on technologies for eventual exploitation of deep sea minerals; and (b) to develop a mechanism whereby the alredy developed technologies can be used in the survey, exploration and exploitation of near-shore resources and resources within national jurisdictions of the developing countries.

The overall project focuses on the industrial exploitation of marine non-living resources and the implications for developing countries (focusing on non-hydrocarbone resources) and will conclude with an international workshop scheduled for september 1993, were the report and related issues will be discussed.

The project is sponsored by the Government of India and is an integrated part of the UNIDO activity area Marine Industrial Technology, coordinated by the New Technologies Unit, the Technology Development and Promotion Division.

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1) Sardana (ed.): **Deep Seabed Minerals - Mining and Related Technologies, A Status Report**, UNIDO, Vienna, 1992.

CONCLUSIONS

Tehnological development

Much of the present day technological research and development would have to address itself to the following areas:

(1) *Developing an efficient sea-floor miner or collector with a view to:*

- *reducing transit time and downtime,*
- *increasing its manoeuvrability to avoid obstacles. reducing turning time and selectively mining nodules, areas,*
- *improving methods of nodule harvesting and crust loosening,*
- *improved dynamic positioning for control of seafloor miner, loading of ore-ships and semi-submersible platform.*

(2) *Use of semi-submersible platforms, rather than standard ships for handling of sub-set mining system, storage and maintenance, transfer and conditions of ore and staff support.*

(3) *Improved efficiency of pyro and hydro-metallurgical processes.*

(4) *Increased mechanisation to reduce personnel costs and improve overall efficiency.*

(5) *Reduction in overall weight and size of mining system.*

Economics

Notwithstanding anything as stated above, fundamental changes which ultimately will alter the economics of deep sea mining include:

(1) *Proposed mining rates of 1.5 to 3 million tonnes per year of dry nodules, is a marginal production rate when compared with on land mines requiring similar capital investment. Increased economies of scale could be achieved through improvements in collector efficiency, rate of collector movement and mining of high nodule density areas. These are all procedures that will require modifications of existing technology. More advanced procedures include multiple miners to collect and deliver to a central raise point and would correspond to multiple faces working in a mine.*

(2) *Additional studies would be required to define, in detail, grade/density distribution within the selected area. As with onland mines, such an approach might significantly alter the initial revenue flow for a project and hence its overall economic viability. It would be advantageous to optimise economic returns of the first "pass" by selectively mining the high grade nodule areas.*

(3) *Significant changes in deep sea mining would result from improving means of controlling deep sea mining and the reliability of the deep sea collector. For this purpose improved use of micro computer systems*

which would be low cost, easily "backed up", have low energy requirements and increase functioning capabilities. This would ensure reduction in the risk of malfunction and lost time for repair of the deep sea miner. Closely associated with the use of micro process controllers would be the development of fiber optics capabilities for data transmission need in the mining process.

(4) As processing costs are the largest cost in deep sea mining, considerable attention shall have to be placed on developing alternative processing capabilities. Researchers has indicated the possibility for "in situ" processing of manganese nodules and crusts utilising a sulphuric acid leach solution which would produce metal sulphide salts for final processing. If finally method of "at sea" surface processing are developed, transporation and disposal costs would be substantially reduced.

(5) New technologies may also improve the lifting devices (pumps) and the pipe string. New and larger pumps, using ceramic parts to reduce wear, corrosion and breaking, are being developed in Japan and new composite pipe materials of equal or greater strength and 1/10th the weight of conventional pipes, are being developed in the United States, Japan and France. These developments will reduce costs, decrease downtime, decrease overall weight of the mining system and allow for new design concepts for deep sea mining.

(6) Robotics and artificial intelligence will play a major role in future deep sea mining enterprises. Their application would result in controlling the exploration and mining systems from remote and would allow for continued evaluation and modification, on the sea floor, or mining operations through onsite analyses of grade and distribution, density, terrian analysis and recognition and for spatial control of mining. These systems would also give the needed support for mining and transporation activities to on board surface systems.

Environmental aspects

Based on information generated on environmental aspects, it can be concluded that as at present, insufficient studies have been done on the biota and the impact on biota of deep sea mining.

More and more researchers are reconverging to the view that intensive research must be undertaken to define the impact of a surface or near surface plane on the environment. Preliminary studies indicated that, because of the local nature of the plume, and the rapid dispersal of both particulate matter and the nutrient rich cold water, the impact of the surface plume would be minimal. Although perhaps generally valid, more research needs to be undertaken to ascertain the specific impacts which may result even from the dispersal material.

This is particularly important with respect to possible crust mining in the central pacific Ocean where impacts on fishing, endangered species, island nations and high bio-productivity are substantial considerations.

In addition, a major research should be undertaken to establish environmental base lines for areas within and adjacent to possible mining *sites. These studies would have to include not only the seafloor but the entire water column to the surface.*

Other studies

A number of other potential studies would also include the impact of (1) ransporation and handling of ores; (2) Processing of ores; and (3) Disposal of processed wastes. All these would add to the cost of R&D activities.

Infrastructure

The long term development of the vast potential resources by the countries would have to take into account the infrastructural development in other related sectors, e.g. ship building, offshore structures, iron and steel manufacturing, metallurgy, electronics, and forecasting. Efforts in this regard nationally have to be coordinated taking into consideration the expertise in the related fields so as to optimise the cost of efforts to achieve the commercial goal.

Cooperation

For developing countries, cooperation at national, regional and international level is a cruzial part of the strategy to successfully utilize the industrial potential of marine non-living resources.

In view of the resource crunch being faced by all the countries and entities aspiring to commercially exploit deep sea minerals, it would be essential that the sub-systems that are developed during the intermediate stages start yielding returns so that further research can be self-sustained with minimum support from the Government and funding agencies. It would be in the interest of all the entities furthering the cause of development of various systems required for successful commercial deep sea mining operations to cooperate among themselves, so that the cost of R&D development can be optimatised and shared.

A large number of developing countries have got economic jurisdictions over vast ares under the Convention of the Law of the Sea, which need to be explored and exploited for generating vast reserves of funds and realising the economic wealth that such areas are holding. For this purpose, the technologies which are being developed for the ultimate goal of exploiting deep sea minerals, could be effectively utilised through an appropriate workshop so that such technologies can effectively generate commercially important activities for the developing countries and appropriate returns for those countries who are developing these technologies.

CONTENTS

1. INTRODUCTION

Since their first recovery from the ocean floor in 1870s during the cruises of the HMS Challenger, polymetallic nodules have been found to cover vast portions of the bottoms of the Pacific, Altantic and Indian Oceans. For more than eighty years thereafter, the nodules were solely of scientific interest. But now, not only ocean engineers and some mining men have become interested in sea bed resources but these resources have become the subject of international organisations like United Nations.

Polymetallic nodules occur as small sphercids varying in diameter from 0.5 to 25 cm in some areas of the deep sea-bed of abyssal plains at a depth of 4000 meters to 6000 meters generally beyond the national jurisdictions of EEZs and continental shelfs. These spheroids are oxides of useful metals rich in manganese content as the primary element, followed by copper, nickel, cobalt, zinc, iron, titanium, molybdenum etc. Due to its higher content of manganese, these spheroids are called Manganese Nodules. The Managanese Nodule is more densely spread and richer in metallic contents in the deep sea than in the coastal water.

The existence of these seabed nodules had been known for years. It was not until 1965 when J.L.Mero studied their economic possibilities that a coherent scientific hypothesis of nodule formation began to emerge. Since then, exploration of manganese nodules have been subjected to intensive research and development.

Based on a conservative estimate of weight and grade of manganese nodules in the sea where recovery in commercial scale is anticipated, one concluded that except for copper, larger ore reserves are in the deep seabed than onland. It was, therefore, quite natural that many companies in the developed countries pooled their resources and expertise to form consortia to develop the entirely new technologies and generate investments needed for their exploration. There was so much optimism in the mid-60s that their exploitation was envisaged to occur within the next few years with profound impact on world economy, trade and metal consumption patterns.

In view of the fact that the nodules richer in metal contents were generally beyond the national jurisdictions of territorial waters, EEZs and continental shelfs, the attention of international lawyers and policy makers was drawn to this. Their situation in the global commons, in turn, called for new legal frameworks for their exploration. These were finally incorporated in the United Nations Convention of the Law of the Sea, and its related resolutions, to which 159 countries are signatories. Protection was granted to countries and entities, in the area of global commons which had made substantial investments in exploration of these important resources with a view to exploiting them subsequently.

The regime, which was finally adopted, has the following salient features:

(i) The country or entity which had invested a minimum of US $ 30 million, and not less than 10 % of which were spent for development of a suitable mine site, would be recognised as "Pioneer Investor" .

(ii) Pioneer Investors would subsequently approach an appropriate International Body for obtaining registration of their status, and for doing so, they would be required to present to this Body two mine sites of equal estimated commercial value, one of which would be allocated to the applicant while the other would be reserved by it, for exploration as a common heritage.

(iii) After registration as a Pioneer Investor, the applicant would be called upon to fulfil the following obligations:

(a) continue to invest a minimum agreed amount to develop the site allocated to it, for mining;

(b) train candidates sponsored by the International Authority to provide technical manpower required for exploring and exploiting the site reserved for it;

(c) transfer nodule exploration technologies on reasonable terms to the International Authority;

(d) periodically report the progress of the nodule exploration programme to the International Authority;

(e) carrying out exploration on behalf of the International Authority in the area reserved for it on reasonable commercial terms, whenever required.

(iv) After the Convention comes into force the Pioneer Investor so registered would be expected to approach the International Seabed Authority with a work plan for approval of further exploration and/or exploitation. Grant or authorisation would be subject to the condition that it would not adversely affect the interest of land based producers of the metals contained in the nodules.

France, India, Japan and USSR were accorded the status of Pioneer Investors in 1982. Four multi-national consortia dominated by USA, UK, Belgium, Germany, etc. were also granted this status. A provision was also made for developing countries to secure such a status upto the entry into force of the Conventioin of the Law of the Sea, by fulfilling the minimum criteria.

Subsequently, in 1987, France, India, Japan and USSR were registered as Pioneer Investors. In 1991, China was also registered as Pioneer Investor. The multi-national consortia have sought to create their legal rights outside the Convention by getting national enactments, as generally the sponsoring Governments have not acceded to the Treaty on the Law of the Sea. The basic differences between those who have not signed the Convention are sought to be resolved through negotiations at the political level to work for the universaliation of the Convention of the Law of the Sea.

2. EXPLORATION TECHNOLOGIES FOR DEEP SEA MINING

2.1 Board objectives of exploration

Objective of deep seabed mineral exploration is to locate, identify and quantify mineral deposits, either for scientific purposes leading to better understanding of their genesis or for potential commercial exploitation. Detailed sampling of promising sites is necessary to prove the commercial value of deposits. Obviously, it would be impractical and too costly to sample the entire seabed areas within the given domain in the detail required to assess the commercial viability of a mineral deposit. Fortunately, this is not necessary as tecniques other than direct sampling can provide many indirect clues that help mining prospectors narrow the search area to the most promising area.

The survey and exploration of the seabed minerals in general and of polymetallic nodules in particular needs to be programmed to generate the following information in a given target area:

- Identification of areas covered with nodules
- Abundance of nodules (kg/m^2)
- Grade of nodules (nickel, copper, cobalt, manganese etc.)
- Specific gravity of wet and dry nodules
- Size distribution of the nodules
- Depth of Ocean bottom (bathymetry of the area)

While the above objectives are similar to those of the exploration for onshore mineral resources, the exploration technologies for deep seabed minerals are vastly different.

2.2 Sampling Devices

For recovering physical samples of manganese nodules and the associated sediments from the sea bottom, three types of bottom sampling devices are used: grab samplers, corers and drag dredges. The sampling devices can be lowered to the bottom from the ship and retrieved by pulling the wire up. They can also be dropped from the ship unattached to any wire, called free fall devices. For rapid sampling of nodules, free fall grab is used extensively due to the relative ease of operation. For collection of samples of modules as well as the associated sediments, box corers or spade corers are used which represent wire operated type of sampling devices. For collection of large quantities of nodules, drag dredges are used which represent open mouthed containers (boxes or bags) that are dragged along the ocean floor.

2.3 Visual Devices

Visual surveys of manganese nodules on the ocean floor and the surrounding topography are carried out by photographic devices that essentially have to operate close to the sea bottom. Two broad types of surveys are conducted

- Spot visual survey

- Continuous visual survey

The spot survey is carried out by still cameras which are normally placed on free fall devices. The continuous visual survey is achieved by continuous bottom photography or underwater television.

2.4 Acoustic Devices

Acoustic devices are extensively used in marine survey and exploration since sound waves have a low frequency and can be transmitted easily in the ocean. There are several types of such devices and depending on the frequency and the power of the sound source used, their applications are specified. The devices that find extensive application in deep seabed exploration are briefly discussed below:

(a) Echo-Sounder:

It is a down looking sonar which performs the basic task of determining water depth. The conventional echo-sounding equipment measures the depth of seabed by sending a strong signal that expands in the water inside a large cone of some 30° top angle. The signal is then echoed by the bottom from a large area. The echo sounder is mounted on the keel of the ship which emits a sound pulse. The reflected echo returns to the receiver on the ship and the length of time determines the depth of ocean bottom.

(b) Sub-bottom profiler:

It is used to study the sediment layers and sub-seafloor features. Sub-bottom profilers use a low frequency high energy sound pulse for bouncing accoustic echoes of sediment layers beneath the ocean floor.

(c) Multibeam echosounder:

Recognition of the limitations of conventional single beam echo sounder led to the development of multi-beam echo sounders. There were two major improvements: first was to narrow the cone of emission or reception to 2-3 degrees and second, to integrate several emitters or receivers as an array in such a way that each looks to a specified area of the bottom. With the system developed, a swath width of more than 4 Kilometers for a 5 Km depth range is continuously mapped at a speed of 18 Kms/Hr. The accuracy of mapping is less than 10 meters in altitude. Thus, for bathymetric mapping of the deep seabed, multibeam echo sounding system is both rapid and accurate.

(d) Side Scan Sonar:

The ability to receive a signal from tiny object on ocean floor (resolution) is determined by the frequency of the sound emitted. The higher the frequency, the smaller the size of an object that can be detected. However, higher frequencies result in higher absorption of sound by the water column. Consequently, the distance to the target must be reduced and when the water depth is too great, the equipment must be placed on a fish towed near the bottom.

Side scan sonar for deep sea applications, called short range sonar, is an instrument which uses high frequency emission. In order to achieve a better resolution the sound antenna is built in such a way that it scans the ocean floor by a narrow beam of sound that results in a swath of information perpendicular to the fish track. The continuous recordings of echoes when the fish moves shows black dots where a strong echo has been received and white dots where there is no echo. A kind of negative photography of the sea bottom is produced where obstacles appear as black patches and hollows appear as white shadows. Thus the products of these surveys are similar to aerial photographs or radar imagery and are called sonar imagery. They are useful for the location of relatively small (micro) topographic features as well as for distinguishing major differences in sediment types.

The existing deep towed side scan sonar can cover a swath of seafloor of 1.5 Km width at a speed of less than 2 Km/h when it is towed from the surface ship with a coaxial cable 6-8 Kms long at a distance of 100 meters above the sea-floor. It can identify objects half a metre high such as outcropping layers of indurated sediments as well as vertical cliffs upto 10m high.

(e) Multi-frequency Exploration/Acoustic System:

The multi-frequency Exploration/Acoustic system developed by USSR and also by Sumitomo Metal Mining Company of Japan is especially designed to provide information on the distribution density and size of manganese nodules on the seafloor on a real-time and continuous basis when combined with acoustic sounding instruments such as narrow beam sounders and the sub-bottom profiler combined with a precision depth recorder with which ocean research vessels are commonly equipped. In this system, contrast in reflectivity of sound from nodule targets and adjoining sediments is used in mapping the nodules.

2.5 Areas of future developments

The currently available seafloor mapping systems provide variety of data demanded by the exploration objectives. However, the next generation seafloor mapping system is required to produce high resolution data at relatively larger speed with minimum interference. The new areas requiring technical development thus include:

- development of a phased array which can beam-form under the high pressure upto 400 atm.
- to miniaturise multibeam electronics as small as possible.
- development of a telemetry system, including composite optical/electrical cable system.
- to stabilise a towfish when it is towed.
- to develop a positioning system, possibly dual SSBL which can determine a position of a towfish as far as 8000 m.

- to develop high resolution subsea measuring system using laser pointer and acoustic ranger.

It is likely that the next generation system may be a towed interferometric system which combines various information with high resolution.

Developments of above nature are already in hand at various institutions, such as, universities like University of Hawaii, Government organisations like Marine Mineral Technology Centre, Hawaii and Metal Mining Agency of Japan as well as private industries like simrad A/S, Sealex A/S, Norway, Benthos (USA) and others involved in marine exploration.

2.6 Data compilation, analysis and dissemination

In addition to acquisition of data on marine minerals as systematic compilation, storage, analysis and dissemination can ensure a reliable identification of potential reserve, in terms of its geographical location, commercial grade and abundance, as well as the various environmental parameters in which it occurs. Various methods for such data management have been used for different types of mineral deposits. For resource estimation of manganese nodules, methods involving nodule coverage, diameter, specific gravity and its recovery in a collector have been suggested and employed by different workers (Anonymous, 1982, Handa and Tsurusaki, 1981; Lenoble, 1980).

Similarly, for compilation of data collected using a wide variety of exploration methods, creation of a data base for efficient storage, analysis and retrieval is most essential. Large quantities of data collected by Ocean Minerals Company, USA, is being catalogued at the Marine Minerals Centre, Hawaii (Morgan and Cruickshank, 1991). A detailed system for interpretation and cataloguing of seabed photography data on nodules (SPHINCS) is being employed at NIO, India (Sharma and Kodagali, 1990).

2.7 Spin off benefits of R&D in marine exploration systems

Research activities on marine exploration system, can lead to a wide variety of newer subsystems and experiences, which will have still wider applications. For example, development of free fall sampling equipment involves development of its components which can withstand the highly corrosive environment which the sampler would traverse during its two-way journey. This research in suitable material development, can be applied to other submarine applications. Similarly, floatation spheres needed to make such system buoyant, at pressure of 500 bars, is a specialised technological development by itself.

Even in case of developing an active deep-tow photography and sounding system, not only the principles of sound velocity and light propagation are applied, but it also leads to an experience in a variety of applications, such as, handling underwater remotely controlled equipment, knowledge of underwater electronics and sensing systems, long distance data transfer, high-pressure instrumentation etc. This knowledge can be used in applications such as development of deep sea mining system, submersible related technology for military applications, as well as civil engineering purposes like cable and pipeline laying, inspection of underwater equipment, salvaging and rescue of lost equipments.

3. SEABED MINING TECHNOLOGY

Sea-bed mining of polymetallic nodules involves collection of potato-shaped concretions embedded in a 100 mm thick layer at the sea bed (approx. 5000 - 6000 m water depth) land and bringing them to the sea surface. The nodules are of 10-200 mm size (average 25-50 mm), reddish brown (iron-rich) or blue black (manganese-rich) in colour having specific gravity of 2-3 T/M and hardness 1-4 on mho scale. It contains about 30% water by weight.

The sea floor is a biological desert with pronounced topographic variations. The water temperature is few degree above freezing point, the area is completely devoid of light and the sediments of the sea bed have poor cohesion (bearing strength around 0.03 Kgf/cm^2).

Research and Development of Polymetallic nodule mining technology has been carried out for last two decades. The systems under consideration have been refinements, though, the basic design concepts remain the same. Three distinct design concepts have till now been used by different international agencies for developing the mining systems. The concepts vary primarily in the engineering approaches used to lift nodules to the surface. These include:

- Hydraulic Mining System (pump Lift/Air Lift)
- Continuous Line Bucket (CLB) Mining System
- Modular or Shuttle Mining System

Two of the three basic design concepts of mining systems, viz. continuous line bucket (CLB) system and shuttle system, have been abandoned or shelved temporarily.

3.1 Hydraulic Mining System

The principle of hydraulics is used for lifting the nodules to the surface ship. A lift pipe attached to the ship extends close to the sea bed and is linked with a collector mechanism. The collector picks up the nodules and feeds them into the lift pipe. The nodules are pumped up through the pipe with pumps installed on the pipe (pump Lift Approach) or are sucked up through the pipe by means of compressed air injected into the pipe from on-board compessor units (Air Lift Approach).

In the pump lift approach, submersible motor-driven pumps are mounted in series at depth of 1000 - 2000 m (decided based on cavitation considerations) for lifting the nodules from sea bed. A 2-phase flow (4% nodule, 96% water) with a flow velocity of 3 to 5 m/sec takes place in the lift pipe.

In the air lift approach, the principle of expanding air bubbles is used to create the lift required to establish a flow of water from ocean bed to the surface. A 3-phase flow (3% nodules, 12% air and 85% water) takes place in the lift pipe. The velocity of water below air inlet (located at around 2000 m depth) is kept more than the sinking velocity of particles (which is around I m/sec).

The basic elements of the hydraulic mining system are: Collector sub-system, Lift sub-system and Mining Ship sub-system.

3.2 Continuous Line Bucket Mining System

A long continuous loop of rope attached with drag bucket is hung from a surface platform in sea such that end of loop touches the sea floor. The loop is caused to rotate so that the buckets during their passage on sea floor excavate nodules and carry them to the surface. Simultaneously, the surface platform is moved in a direction perpendicular to the plane of the loop on a path having width equal to the length of the platform is swept across the sea bed.

The basic elements of this system are: Bucket sub-system, Rope sub-system and Mining ship sub-system.

The bucket clipped to the rope loop at regular intervals collect the nodules and dislodge the sediments from them, as they graze the sea floor. A braided polypropylene rope circulates on the ship thru' umbrella type wheels and is caused to rotate by tracing device on-board the ship. Hydrodynamic separators are provided to aviod tangling of the rope. Buckets are attached to rope at stem deck and filled buckets removed at Bow deck and unloaded on deck storage.

Mining ship sub-system is similar to that described for hydraulic mining system except that the pipe storage and handling facilities and deck crane for handling underwater components . e not required. Instead, drive arrangement for rope and its storage and handling facilities are provided.

A two-ship CLB system is preferred to single-ship system as it avoids sub-sea tangling of ropes.

3.3 Modular Mining System

The shuttle unit (collector) with ballast material (weight of ballast in water equals weight of nodules to be collected in water) is made weightless in water with the help of buoyancy elements. The shuttle unit launched from the surface platform propels down to sea bed against hydrodynamic resistance alone. The unit moves on sea bed and collects nodules as it simultaneously ejects ballast material of equal weight (in water). When all ballast material is ejected and the weight of unit becomes zero or negative, the unit propels to surface and docks with surface platform, where it is unloaded, serviced and reballasted for new mining cycle.

Basic elements of this system are: Collector unit and Surface platform.

The collector unit is provided with on-board energy source and necessary sensors and controls to enable it descend/ascend and lift nodules while being propelled by archimedes screw, as per remote commands or on-board program.

The Surface Platform is provided with:

- Moonpool for launch and docking interface.
- System to command collector unit thru' remote acoustic commands or programs on-board the units.
- Deck space to unload, inspect and maintain recovered unit.

- Facility to store and load ballast material prior to launch of unit.

3.4 Comparison Between Various Mining Systems

The continuous - line - bucket (CLB) system is simple, flexible in operation, potentially energy efficient and involves lesser cost but has low recovery rates besides the possibilities of tangling of ascending and descending segments (which may result in close down). This system has, therefore, been abandoned.

The remotely controlled shuttle (modular mining) system is yet to be developed and extensively tested in shallow and deep sea waters to establish its reliability. Besides, cost of moving of tailings from a distant onshore processing plant to mine site for use as ballast material may be prohibitive. This system has therefore been tem porarily shelved and is considered as a future second generation technology.

The development of hydraulic (pump lift/air lift) system is based on the technology and experience gained in operating oil risers in deep waters and the knowhow built in connection with slurry transportation of minerals at sea and on land. Hydraulic system is currently considered most effective although long-term testing and consequent refinements are necessary to establish its reliability for commercial-stage mining (3 million tonne dry nodules/year capacity). The best judgement for pilot test appears to be a combination of centrifugal pumps and air lift systems.

4. ENVIRONMENTAL IMPACT OF SEABED MINING TECHNOLOGY

The study of impact of deep seabed mining on oceanic ecosystem involves three components:

(a) Estalishing environmental baselines of the selected parameters likely to be encountered during nodule mining (Environmental Characteristics),

(b) Potential environmental effects of nodule mining and developing prediction capabilities, and

(c) Developing appropriate environmental guidelines.

It may be appreciated that it is not scientifically and economically possible to develop very detailed baseline information on the ecology of all offshore environments in a relatively short period. Accordingly, the consequences of a variety of mining scenarios cannot be precisely predicted. In the very near future, therefore, environmental impact statements will presumably be prepared to identify site specific problems prior to the commencement of mining operations.

4.1 Environmental baseline information

The pre-mining envirnomental characteristics will serve as a data base for measuring environmental consequences associated with mining. Environmental parameters that are specifically relevant to the mining activities and need systematic studies over a period of time and space. These parameters represent selected characteristics of the upper water column and the lower column including the seafloor.

Characteristics of the surface waters including seasonal variations is important for modelling surface plume dispersion and inference on potential biological impacts. Lower water column and seafloor characteristics are directly relevant to benthic impact.

4.2 Deep sea environment

In the deep-sea, the abundance of animal life decreases with increasing depth and distance from land. Deep sea animals are predominantly restricted to the surface of the seafloor and upper few inches of bottom. It appears that the species, particularly catalogued at present and the information on their life cycles is inadequate. The density of animals is low but diversity is considered to be high. In these regions, the low total number of animals is thought to reflect the restricted food supply, which comes from either residues raining into the deep sea from above or from in situ production.

4.3 Deep sea mining studies - possible impacts

All estimates and inferences regarding environmental impacts of deep sea mining draw heavily on information from the Deep Ocean Mining environmental study (DOMES) funded by NOAA. Till now, this seems to be the only systematic long term research programme conducted in very deep water. Extrapolations from these studies to other ocean sites rest on the assumption that in general, the abyssal ocean is a much more homogeneous environment than shallow water environments.

The mining scenario presumed removal of nodules from the deep seabed by means of collector driven along the seabed at about 2 miles per hour. Animals on the seafloor directly in the mining path or nearby would be disturbed by the collector and the subsequent sediment plume. In addition, when the nodules reached the mining ships, the remaining residue consisting of bottom water, sediments, and nodule fragments would be discharged over the side of the ship, resulting in a surface discharge plume that might also cause adverse impact.

The study carried out under DOMES programme, concluded that while there were 20 to 30 possible negetive impact from deep sea mining, only 3 were of sufficient concern to be investigated.

The first of the three important impact occurs at the seabed. First, the collection equipment will probably destroy benthic biota, an impact which appears to be both adverse and unavoidable. The degree of disturbance depends upon the kinds of equipment used and the intensity of mining. Most benthic animals in this region appear to be tiny detritus feeders that live in the upper centimeter of sediment and are fed by organic material that falls from upper waters. In the worst scenario, the benthic biota in a very small part of the mining areas may be killed due to impacts from first generation mining activities. Although recolonisation is likely to occur after mining, the time period required is not known. No effect on the water column food chain is expected.

The second important type of impact identified is due to a benthic plume or "rain of fines" away from the collector which may affect seabed animals outside the actual mining tract through smothering and interference with feeding. Suspended sediment concentrations decrease rapidly, but the plume can extend tens of kilometers from the collector and last several weeks after mining stops. No effect on the food chain in the water column is expected due to the rapid dilution of the plume. However, mining may interfere with the food supply for the bottom-feeding animals and clog the respiratory surface of filter feeders.

The third impact identified as significant is due to the surface plume. Under a possible scenario, a 5,500 TDP mining ship may discharge about 2000 tonnes of solids and about 3 million cubic feet of water per day. The resulting surface discharge plume may extend about 40 to 60 miles with a width of 15-20 miles and will continue to be detectable for 3 to 4 days following discharge. Such plumes may affect the larvae of fish, such as tuna, which spawn in the open ocean. The turbidity in the water column will decrease light available for photo-synthesis but will not severely affect the phytoplankton populations. The effect may be well within the realm of normal light level fluctuations.

The post DOMES research suggests that the problem of surface plume may not be as serious as was considered before due to rapid dilution and dissipation. However, another potential effect has been identified - that of thermal shock to plankton and fish larvae in the immediate vicinity of the cold water discharge, at the surface of cold deep water. However, except for mortality of some tuna and billfish larvae in the immediate vicinity of the cold water discharge, adverse effects appear to be minimal.

4.4 Environmental guidelines

It will be required to develop an environmental guidelines document including environment impact statements prior to commencement of mining operations or prior to submission of a work plan. Such a document will be based on detailed environmental baseline information and suitable predictive models for environmental impact.

Before mining commences in the deep sea, it will be required to identify two reference areas which should be maintained for sampling during the operations. One such area will be sufficiently removed from the impact area to serve as a control. This is referred to as the "preservation reference zones" in which no mining shall occur to ensure representative and stable biota of the seabed in order to assess any changes in the flora and fauna of the marine environment. The second area may be adjacent to the mining area called "impact reference zones" which will be used for assessing the effects of mining operations in the area.

While systematic studies on long term basis on environmental impact of deep seabed mining were earlier carried out by NOAA under the DOMES programme, some recent studies and programmes of German Companies and institutes supported by the Government are of special interest. THETIS Technologic GmbH supported by German Ministry for Research and Technology have initiated two pronged studies in this regard. The basic approach involves design and development of seabed mining technology in general and of collector subsystem, in particular, incorporating environmental friendly features. Studies are concentrated on controls, pick-up efficiency with minimum cutting depth, optimisation of traction and trafficability and material selection such that the resultant self-propelled, hybrid collector subsystem is environmentally acceptable. In the second set of studies, experimentations have been designed to study on a long term basis the nature and extent of impacts of the operations similar to the deep seabed mining.

Studies undertaken by the Japanese agencies involved in seabed mining and related developments include development of simulation models for assessment of the impact of mining activities on the oceanic environment including the benthic eco-system. These agencies have commenced an environmental impact survey to evaluate the simulation models through indoor experiments, field experiments and observations.

5. PROCESSING TECHNOLOGY

During period of 1970 to 1980, the world-over witnessed large involvement of several research institutions, laboratories and consortia for development of viable process routes. Subsequently the pace of activities had considerably slackened because of various factors like slow growth of nickel market vis-a-vis economic viability, development of mining capabilities, high costs of R&D etc. Till date no one has processed nodules continuously over a long interval of time at pilot plant scale. As against the stage of development related to process development for nodules, metal extraction from commercial processing of land based copper, nickel or cobalt bearing materials have incorporated various process improvements. The last few years have witnessed the introduction of several new reagents for metal processing. Some of the earlier nodules processes developed may have already reached some stage of obsolescence. Since most of the cost of producing metals from nodules are related to the processing sector, constant updation of R&D efforts is required to keep the developed process competitive in the volatile metal markets.

The large scale of operations warranted by nodules processing would need constant attention with regard to scale up aspects of conventional equipments used during processing. The present chapter endeavours to stress that it would be necessary to continue developmental activities with regard to processing with a view to update the existing state of knowledge and also to integrate, wherever possible, experience gained by processing of similar land based resources into the proposed routes for nodules processing. Since profits from seabed mining can only be a matter of future speculation, it is essential to have organised involvement and support for developmental efforts for the nodules processing activity.

5.1 Progressive options

An initial reaction to processing options is that nodules are contaminated managanese ores. However, presently, the wet, impure 30% Mn ore cannot compare economically with dry pure 45 - 50% Mn ore available commercially. A decision to commit substantial capital funds into facilities to produce managanese from nodules may be difficult to justify for certain research organisations/countries. It might be assumed that the porosity of the ore would make direct leaching viable. However, kinetics of nodules leaching process bring out that it is necessary to use reducing agents to attack tetravalent managanese oxide matrix, thereby releasing the valuable materials.

Both pyrometallurgical and hydrometallurgical processes for nodule treatment have been examined. As a result of the complexity and polymetallic nature of nodules, it is not possible to use purely pyrometallurgical techniques to produce separate metallic products of the contained metal values. However, as a pretreatment step, pyrometallurgy can be used to concentrate the metal values and alter the physical, chemical and mineralogical characteristics to achieve enhanced selectiveness and dissolution rates during subsequent hydrometallurgical processing. Also, the total amount of material sent to leaching can be decreased, thereby affording reduction in processing costs.

5.2 Process choice for the future

In view of the various uncertainties in the development of a viable process route and the stage of piloting with regard to different processes, it is extremely difficult to justify one process route for eventual commercilisation. Besides techno-economic viability, the choice of a process route would critically depend on whether manganese is to be recovered.

Various groups have worked out techno-economics for a 3 M TPA nodules commercial production based on the limited information available. The reports are largely based on Cuprion process with a downstream solvent extraction route for metal recovery, reduction roast ammoniacal leach solvent extraction route and reduction roast-smelting solvent extraction route. These flowsheets with adequate material and energy balances are described by USBM and as brought out previously, there are ample number of alternatives for the downstream section. These studies indicate by and large that future metal prices would have an important effect on the overall economics. For example, rates of return have been computed over ranges of metal prices such as given below:

Cobalt	14,000 - 37,000	$/ton
Copper	1,300 - 2,500	$/ton
Ferro-manganese	250 - 570	$/ton
Nickel	5,700 - 9,300	$/ton

It has been ointed out that in particular the nickel prices need to shoot up towards considerably higher values for such a high risk venture to succeed. Also, it is extremely important to maximise recoveries for various metals, especially nickel. It is doubtful whether the present state of art for nodules processing allow a maximum limit to be present for commercial scale processes based on extrapolation of reliable pilot scale data. As such, it is difficult and inappropriate to make a process choice based on preliminary techno-economic indications.

Process comparisons have also been made from the point of view of energy requirements for various processes producing metals from sea nodules. Energy consumptions have been calculated for mining and transportation of nodules, processing, waste treatment and disposal and transportation of final products. For various 3-metal recovery route, annual energy consumption estimated were virtually identical. However, a 3-metal route based on smelting had a substantially higher energy consumption as compared to other 3-metal routes. Different 4-metal recovery routes also showed virtually same energy consumptions. The various data provided show directions of future work to be conducted for possible energy savings rather than inferences on choice of process.

6. INTERFACE WITH INDUSTRIES

The previous chapters have outlined the state of technological development in the field of exploration, mining, processing and environmental aspects. Cardinal to meaningful development of new technologies in any area is the need to inter-twine the efforts of R&D institutions, design engineers and the industry within the overall guidance and control of the financing agencies, may it be Government or any other corporate body. A strong feed back mechanism has to be in place to effect corrective measures at different stages during the period when technology for commercial exploitation is being perfected. To ensure that the technology so perfected does not become obsolete because of breakthroughs taking place elsewhere, the basic researh institutions which develop initially the technology, have to keep pace with the performance of the systems finally adopted by the industry and monitor on a continuous basis the cost effectiveness of existing technologies and level of performance.

Development of deep seabed mining technologies is also no exception to the above stated principle. It is easier to implement this principle in a technologically advanced environment where it is possible for one of the players to take a lead and to persuade the other players to join to make the end as a common endeavour.

6.1 Trends

Initially, the development of deep seabed mining technology took place purely as private initiative in USA, France and Germany, particularly when it was thought that exploitation of deep sea mineral resources was possible in the near time frame. Such organisations in these countries which took interest in the development of these technologies were not very strong commercial entities but were also endowed with very strong R&D Groups in almost all the disciplines which required to contribute to the development of the end technologies. However, when the deep seabed mineral resources receded into the distant possibility as far as commercial exploitation was concerned, these entities, which were generally in the private sector, withdrew from these activities after positioning themselves strategically; yet a substantial part of their findings were passed on to R&D institutions, including Universities, for safe custody of their results under some agreement so that the commercial interests of such entities which took the pioneering interest in the development of these technologies were taken care of.

Wherever substantial Government funding was available for carrying out this programme, e.g. in France and Japan, the development of these technologies have been further continued in a very systematic manner.

To illustrate the inter-relationship between the R&D institutions and the support that these institutions need from the industries and vice versa, it would be interesting to study the practice that has been adopted in Japan.

The Ministry of International Trade and Industry started the research and development projects of manganese nodules mining system in 1981 with a clear objective of developing the hydraulic mining system in which manganese nodules would be collected by a towed vehicle on the ocean floor and transported in a slurry of sea water and nodules through the lift system on to the mining ship.

To achieve the objectives of the project, the Agency of Industrial Science and Technology promoted a Technology Research Association of Manganese Nodules Mining System. This Association was also supported by New Energy and Industrial Technology Development Organisation (NEDO). This Association conducted the R&D programmes effectively by coordinating its members, which are 19 private companies and one agency. Thus, from the conceptual stage itself, the authorities responsible for planning the execution of the project visualised the multidisciplinary nature of the project even at R&D stage and therefore pooled the expertise from amongst the various national resources available within the country, onstensibly not only to avoid the need for duplicating the efforts but also to avail of the expertise and opportunities available.

At the apex, the national R&D programme is coordinated by two organisations, viz., the National Research Institute for pollution and Resources (NRIPR) and the Technology Association of Manganese Nodule Mining System(TRAM). The former is entrusted with the responsibility of performing the basic experimental work and theoretical analysis for the phenomenon of collecting and loading nodules and for determining the environmental effects of mining in the ocean. The latter performs the R&D of the actual Manganese Nodule Mining Pilot System and the pilot scale ocean test in the South Sea North Pacific Ocean.

The R&D stage was completed and the basic design of an integrated ocean mining test system was established at a cost of about 4,600 million yens in 1985.

It may be interesting to note that TRAM, which was the supervisory agency for developing a Manganese Nodule Mining Pilot System, consisted of 19 private companies and one agency. The constitution of TRAM provides that interested parties in the private sector are welcome to join TRAM and even foreign countries are welcome to do so and will be treated like any other Japanese private sector company. It is mandatory for these countries to become members of TRAM and they should assume responsibility for the activities of TRAM just like any other Japanese companies.

Once systematically the basic research was completed to the satisfaction of the peer group, since 1986 the detailed design of the mining test system has been developed and necessary machinery and equipment have been started to be manufactured. While developing the basic test system as above, the facilities that are available in the laboratory where basic design concept was initially thought of, are yet available to the TRAM which again ensures that duplication of efforts are avoided and the experts who were responsible for developing the basic design are still available while the test mining system is being perfected.

The Japanese have also started looking very recently into the processing aspects of nodules. Towards this end also, a somewhat similar strategy has been followed and the giant multinationals engaged in the nickel and cobalt are coordinating the efforts of the Japanese research workers in perfecting the ultimate process that they will choose. Development in France was also on similar lines.

In India, where the development of deep seabed mining system has been taken up very recently, a somewhat similar model to the Japanese model has been contemplated. The Department of Ocean Development, the agency identified by Government of India, as a nodal agency to carry out the programme for development of deep sea mineral resources, have drawn up a list of various subsystems that go into the development of deep seabed mining system i.e. survey and exploration, mining and processing. This list has been made available to the Indian industry to make an in house assessment to conclude as to what type of subsystems they are in a position to develop without further R&D efforts and at the same time to identify the subsystems which the Indian industry can develop on thier own by infusing some efforts in R&D. Industry may also come to conclusions about some subsystems, which it thinks it may be capable of producing on its own, immediately or after some efforts, but may also decide not to produce, on commercial grounds. While the industry is carrying out the exercise on the above lines, a national level Committee involving national scientific Laboratories having expertise in different disciplines has been constituted to pool in their efforts for refining the techniques in survey and exploration, processing and in the development of mining techniques. Interestingly the Chairman of that Committee and the Chairman of the Committee from industry, which would look into the capacity of the Indian Industry to produce various sub systems, is the same person so that a mechanism of coordination exists between the industry and the R&D institutions right from the beginning.

Though India's industrial base, diversified as it is, is not yet the same as that of developing countries, some large industrial houses have expressed their readiness to take on the development of various equipments that may be needed at the initial stages of developing the mining system.

6.2 Problems and policy perspectives

In almost all the countries where efforts have been taken or are on to refine existing marine technologies other than the technologies required for exploitation of deep mineral resources, there has been a deep commitment of industry to R&D and R&D to industry. Such technologies have generally become self-paying and industry is capable of funding further in R&D.

The basic difficulty that is facing the development of technologies for exploitation of deep sea mineral resources, is lack of interest displayed by big companies because of uncertainty in immediate commercial viabilities of such projects, and the Governments in those countries where this programme was only very recently being started by them have also shown reluctance in infusing further resources at the scales required. Therefore, it becomes all the more imperative that some strategies are devised so that the efforts in developing these technologies become self-sustaining. One obvious strategy that could be is that the industry takes upon itself the task of using the intermediate results in offering their services to those countries where such technologies after some refinements can be utilised for developing the resources within their national jurisdictions, EEZs and continental shelfs. This would give the opportunity to the industry and also R&D institutions to test the performance of their efforts in actual field conditions while the revenue can keep coming for developing in-house technologies. This would also serve the purpose of the developing countries who otherwise are left unaided in exploiting resources which are otherwise available right at their door steps.

Because of shrinking resources and the increasing cost of research, there is a case not only for greater interaction between the industry and R&D institutions within national jurisdictions but also for international cooperation so that expertise gained by the various experts in similar disciplines can be pooled to get maximum return out of the investment that is being made internationally. This would necessarily require a greater opening up of the facilities by those who are already ahead in the race, on the consideration that initially those who joined this internationl corporate mechanism may ultimately contribute to make the end result more commercially viable. To illustate this point further, it can be safely concluded that the users of a system like collector capable of operating in deep sea areas would not be many and perhaps it would be much easier for a commercial entity developed out of international cooperation to provide such system to the users at reasonable rates which would not only be beneficial to the users but would go a long way in making the commercial projects viable.

7. FUTURE PROSPECTS

The primary reasons for this delay in exploitation can be classified into at least the following areas:

(a) Economic

(b) Technological

(c) Environmental, and

(d) Policy

7.1 Economic Considerations

From a purely corporate perspective, the use of conservative long-term metal prices in deep sea mining ventures often results in such ventures being evaluated on a "worst case scenario" basis. This scenario is more compounded because of the early experience in evaluating deep sea mining ventures for nodules where unrealistic longterm prices for metals were used. Deep sea ventures envisaged today are towards production of varying amounts of manganese, copper, nickel and cobalt from the mining of manganese crusts and copper, lead, zinc, silver and gold from mining of polymetallic massive sulphides. For all these metals, adequate sources of supply presently exist from land resources. For the near term and intermediate (15 to 25 years) term, global reserve of these metals are adequate for world demand. Thus, deep-sea minerals will be developed vigorously in the following circumstances:-

(a) If supply disruptions occur or are likely to occur;

(b) If onland mining costs exceed deep sea mining cost; or

(c) Worldwide or regional demand for metals increases in an unforeseen manner.

All these are factors of uncertainty, with respect to supply and demand. The corporate analysis would still like to make an economic judgement on the basis of "worst case scenario".

Deep sea mining is a new activity for the mining industry in which risks are obviously high because of both economic and technological uncertainty. In such circumstances, higher than normal internal rate of return for a project is required to compensate for the high risk of the project. A.D. Little (1984) has suggested that a nodule mining venture would need to achieve a 30% IRR as invested funds - substantially above the 12-16 % achieved in onland mining ventures. For a workable analysis, an IRR rate of 18-22 % is necessary to convince the prospective investors to evince interest. Nevertheless, a major factor to be assessed in evaluating a deep sea mining venture will be the relative costs of onland production from existing mines and the costs of developing comparable onland deposits. Onland mining developments will generally be undertaken, using existing technology and reasonably certain costs. Thus, deep sea mining activity would have to take place on deposits that are either substantially higher grade than onland deposits or deposits which are easier to mine and/or process, resulting in lower operating costs per ton of ore than on onland mines.

Coupled with the above scenario, potential investors like the International Consortia, are looking with expectations on the scenario of the United Nations Convention on the Law of the Sea and they would have to take dicisions if the investments are finally to be undertaken under the Reciprocating States Agreement or under the United Nations Convention on the Law of the Sea. It is certain that development of crusts and polymetallic sulphide deposits, would, in most cases, take place under the economic regime of nations within whose Economic Zone they occur.

All the factors mentioned above are external economic issues which, however, are of particular importance in that the uncertainty substantially adds to the risk of an already high risk enterprise, further resulting in decision making being made on a "Worst case scenario".

Several analyses has been carried out on the economics relating to deep sea mining of manganese nodules and manganese crusts. No studies of polymetallic sulphide mining economics are presently available.

Capital and operating costs for processing, in both nodule and crust mining, are anticipated to constitute 50 to 65 % of all costs whereas capital and operating costs for mining and transportation ranges from 20 to 30 % and 10 to 25% respectively, of all costs. Studies show that perhaps deep sea mining ventures require capital expenditures of US $ 750 - 955 million, comparable to the costs associated with the development of a largescale onland mine. However, a similar mine so developed onland would produce approximately 4 to 6 times the quantity of ore for the same investment. Thus, particular atention needs to be paid in achieving the economies of scale in deep-sea mining as are achievable onland. If such economics of scale could be achieved with marginal increase in capital and operating costs, the economic viability of deep-sea mining venture would improve.

Another interesting feature that emerges from the economics analysis is that the high risk portion of deep sea mining is associated with 30% or less of the total capital and operating costs (and this would further decrease to 10% or less when only the under sea mining is considered as the only high risk endeavour) whereas 50% or more of the total capital and operating costs are associated with very low risk, proven transportation and metallurgical processes.

The most recent economic analysis of deep sea mining venture has been completed for a manganese nodule mining venture proposed by France in 1989. The revenues generated by the sale of the produced products have been estimated to be US $ 495 million per year or US $ 440 per tonne of dry nodules. An IRR of 12% has been indicated with a six year pay off period for the project. For additional cases it was found that IRR ranged from 10 - 14%. In this study, although the mining and transportation costs are similar to costs used in other studies, the highly favourable IRR generated is largely attributed to high recovery efficiencies in the processing portion of the mining venture. The IRR projected, however, correspond to the onland mining ventures and given the high risk nature of deep sea mining, the results may at best be considered encouraging.

7.2 Technical Factors

Almost all the developments that are taking place in the mining system and transport system are based upon existing marine and offshore petroleum industry concepts and technologies. Significant changes in the economics of deep sea mining could result from technological changes in the mining, transportation and processing aspects of deep sea mining.

7.3 Environmental Issues

Because of increased awareness of environmental issues globally, considerable attention will have to be given to assessing the environmental impacts of a mining venture. More effort will need to be directed toward asessing and mitigating the environmental impact of mining.

The environmental impacts and costs have been in a systematic manner studied by the US National Oceanic and Atmospheric Administration sponsored Deep Ocean Mining Environments Study programme, conducted from 1975 to 1980, for manganese nodule mining and the Manganese Crust Environment Impact Study Project is presently being completed for crust mining in the Hawaiian Archipelago and Johnston Island. The results of both studies are similar in terms of environmental impacts and differ primarily with reference to factors associated with topography and bottom type, i.e. crusts occur on slopes with few sediments whereas nodules occur on abyssal plains carpeted with thick sediments. Consequently, the mining activities differ in their potential for resuspension of sediments. Three critical areas, according to these studies, need to be studied more closely:

(1) The collector will destroy benthic biota which has both an adverse and unavoidable impact.

(2) A bottom benthic plume will be produced away, from the collector, which may extend over several kilometers.

(3) A surface/near surface plume will be discharged consisting both of sediments and particles, and of nutrient rich cold water.

7.4 Policy Issues

A quick review of the history of deep sea mining research indicates that in early 1970s, industry interest was very high, specifically for nodules, and industry provided the bulk of the research funds. In the late 1970 and early 1980 industry interest has declined, funding levels have dropped and governments have begun to play a larger role. From the mid-1980s onward only those programmes with substantial gevernment support have continued. With no near-term economic exploitation of deep sea minerals in view, the interest of industry in deep sea mining will continue to be in limbo. Therefore, government support to deep sea mining researches has to be increased if semblance of maintaining the capability and research programmes is to be continued. Because of money considerations, Governments will have to play a greater role in respect of supporting marine environmental research on the impact of deep sea mining. Once mining is round the corner, Government will have a further role in monitoring and enforcing environmental compliance, as economic costs that should not be borne by the mining venture. The Governments will need to carefully assess the economic impact of environmental legislation and policies, under which deep sea mining will take place, and the economic viability of the mining venture. A cut off would have to be developed to ensure that while the environment is protected, deep sea mining does not become too costly because of environmental regulations.

Basically, the following fundamental questions arise which ultimately must be addressed and resolved if deep sea mining is to proceed:

(1) Will the emerging economic changes in the world economy overall and the metals industry particularly, provide for a stable economic environment for development?

(2) Will the existing technologies of onland mining and offshore petroleum, provide the basis for economic deep sea mining or will altogether new technologies, mining concepts and mining systems be required?

(3) Whether adequate resources for the modification of existing technologies for developing new concepts would be available through outright grants or through generation of resources, by exploiting the emerging technologies while optimising their use for exploitation of near-shore resources in the country or countries where such developments are taking place or in developing countries which need to exploit their near shore areas to make use of the jurisdictions vested in them under the convention on the Law of the Sea. What type of international cooperation mechanism in the field of development of new technologies and their intermediate uses would emerge to reduce the cost of those who are engaged in developing such technologies?

(4) Will present environmental costs and constraints increase, with increasing global environmental awareness, to a point that deep sea mining is further delayed?

(5) Will deep sea mining be undertaken under the Convention on the Law of the Sea or under the agreements of the Reciprocating States or a combination of both?

The development of deep seabed mining would eventual depend on the pace with which the industrial activity is spurred to translate the R&D efforts into actual action and the willingness and zeal of the industry to take new challenges.