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A MARKET ANALYSIS FOR REMOTE MANIPULATOR SYSTEMS

Prepared For:

Aerospace Systems Directorate
Department of Industry, Trade, and Commerce

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1.0 INTRODUCTION

In 1976, Philip A. Lapp Limited was commissioned by Spar Aerospace Products Limited to complete a market survey of the potential applications for the technologies and hardware which would be developed as a result of Canada's participation in the U.S. Space Shuttle program.

The United States is scheduled to launch the third manned orbital mission of the Space Shuttle in the Fall of 1979. This vehicle will be the first flight of the Shuttle Remote Manipulator System (SRMS). In many respects, it will represent the most advanced design in the world in remote manipulator technology. The Space Shuttle RMS will be used to place payloads in orbit, retrieve payloads, perform some servicing operations, and support extra-vehicular activity by astronauts. In the future, more advanced manipulators may be used in the construction of orbiting space stations and in the exploration of other planets.

A Memorandum of Understanding has been signed giving Canada the exclusive right to development of the Space Shuttle RMS in return for an agreement by NASA which includes, among other conditions, the purchase of the hardware required for a limited number of future missions. Spar Aerospace Products Limited has been selected as the prime contractor to design, develop, and manufacture the Shuttle RMS. Spar has formed a consortium of Canadian companies including RCA Limited, CAE Electronics Ltd., and Dilworth, Secord, Meagher & Associates Limited to assist in the execution of this project.

Participation in the program has several distinct advantages for Canada. Through a commitment of research and development funds, Canada will have continued access to a launch facility for future Canadian satellites. Also, the Shuttle RMS program will enable Canadian industry not only to maintain but also to enhance its present capabilities to design, develop, and manufacture products for future space programs, particularly in the prime contractor role and through the acquisition of additional relevant technologies.

Many of the developments from the Shuttle RMS program could be of direct benefit to Canada. One example is represented by the programs which will be required in the implementation of the Oceans Policy. The key element of this policy, announced in July, 1973, was that Canada "develop and control within her own borders the essential elements needed to exploit off-shore resources". To maintain sovereignty in coastal waters, particularly in ice infested regions, significant developments in underwater technology will be required. The ability to effect search and rescue, and to conduct inspection and maintenance of underwater systems, will require the availability of underwater vehicles equipped with advanced manipulators.

The resource industries are investigating offshore reserves and the technology which will be required to exploit the vast potential. The oil and gas industry already is involved in offshore production facilities. The use of submersibles in the North Sea oil and gas fields is growing, and should continue to grow as exploration activities extend to depths beyond the present capabilities of divers.

Remote manipulators also have applications in industry. Canada is not the only industrialized nation faced with increasing labour rates and concerns over productivity and dull, repetitive jobs. All are factors which lend themselves to a consideration of the introduction of automation. Some countries, notably Sweden, Norway, and Japan, are introducing industrial robots into their factories in an effort to reduce labour content and overcome the shortage of some skills. The use of industrial robots is increasing in these countries.

The proportion of nuclear power in the energy grid of countries such as the United States, Japan, Germany, the United Kingdom, France, and Canada is increasing; and, concurrently, the need for remote manipulator systems to handle spent fuel and irradiated material.

These are only a few of the potential markets which can be identified for remote manipulator systems. The scope of the work completed for Spar included not only identifying these potential markets but also reviewing their relevance to the work on the Shuttle RMS, describing the present status of each market, and estimating the opportunities for Canadian industry, and particularly for Spar.

The analyses of applications in the space, underwater, nuclear, and industrial markets concluded with an estimate of total potential sales for Canadian industry of $1 billion by the end of this century. The report also concluded that some of these opportunities would not be appropriate for Spar, or the other members of the consortium, either because of the product, the size of the market, the type of customer, or the expected return on investment.

However, it was recognized that some of the potential markets, including many not analysed in detail in the report, could represent appropriate opportunities for other Canadian companies. The report prepared for Spar Aerospace Products Limited contains many references to information, financial data, and corporate strategies which are confidential to the company. Therefore, in order that the market assessments and projections could be made available to other Canadian companies, Philip A. Lapp Limited, with the consent of Spar Aerospace Products Limited, entered into a contract with the Department of Industry, Trade, and Commerce, to prepare a report which would present useful information and statistics on the relevant markets for the remote manipulator technology while, at the same time, keeping confidential the financial information and strategies provided by Spar for the original report.

The four market assessments prepared for Spar discussed the present market and the potential applications of remote manipulator technology in some detail. The projections of potential market size on the other hand were limited to reviews of projections in the literature and simple extrapolations of factors and trends. The objective was to achieve a first approximation of the potential size of each market. The report proceeded to determine the approximate return on investment in each market and to present appropriate marketing strategies for Spar.

The sections covering estimated return on investment and proposed marketing strategies are excluded from this report. Instead, a section has been added which discusses the present status of the Canadian machinery market and proposes a methodology for collecting additional information and data on the one market area, industrial automation, which would seem, at this time to be the most appropriate for Canadian industry.

The report contains eight sections including the introduction. The second section is devoted to an introduction to the possible markets for the application of developments in remote manipulator technology and an appraisal of the relevance of the developments to the market. Sections three to six cover the projections for each of the four markets selected for analysis (space, underwater, nuclear, and industrial) *.

Section seven presents a review of the present status of the Canadian industrial machinery market. The conclusions in section eight also include a proposed methodology for learning more about the present trends and attitudes towards industrial automation in Canada and therefore the prospects for an industry based on the possible developments from the Shuttle RMS program.

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* The projections for Spar Aerospace Limited covered the period 1976 to 2000. Information on possible programs beyond 1990 was very limited in all sectors. Therefore, for this report, the projections were made only to 1990.

2.0 THE PROGRAM OUTPUTS AND THEIR POTENTIAL APPLICATIONS

2.1 Definition of Terms

The term 'remote manipulator' is often used interchangeably with terms such as 'teleoperator', 'limited sequence manipulator', and 'robot'. For this study, we have adopted the following definitions to distinguish the terms. The important element in these definitions is the role assigned to man in the control loop. In this study, remote manipulator defines those applications in which man is the primary element in the control loop, and an active participant in the command and control functions. Limited sequence manipulators represent the first stage in which man is not an integral part of the control loop. All command and control operations are pre-programmed and there is no element for decision-making. Robots, which represent the next step, also are pre-programmed but the programming usually includes decision-making elements. For example, a robot may be trained to accept or reject objects based on size and shape.

The term teleoperator has been used in the literature to describe systems in all three categories. For this study we shall use the term "remote manipulator" to refer to all systems with man in the control loop, the term "limited sequence manipulator" to include all systems in which each action is programmed, and the term "robot" to define systems in which the control function is pre-programmed but includes decision making capabilities (even though the decision making capability also may be pre-programmed). The new advances being made in artificial intelligence would be grouped with robots.

The Shuttle RMS would be termed a "remote manipulator" based on this classification. The major part of this study will be concerned with applications of remote manipulators (man in the control loop), and their components. However, there are many similarities between remote manipulators, limited sequence manipulators, and robots. The systems, sub-systems, and components which are being developed for the Shuttle RMS program could find application in important markets for limited sequence manipulators and robots.

2.2 The Program Outputs

The outputs of the Shuttle RMS program can be grouped into either hardware, facilities, or skills which include management skills and technologies (Figure 2.1). The major items of hardware on the Shuttle RMS, termed major sub-systems, and their constituent minor sub-systems are identified in Figure 2.2. The major sub-systems include:

1. manipulator arm sub-system (MAS/S)
2. displays and controls
3. manipulator controller interface unit (MCIU)
4. software
5. associated ground support equipment (GSE)

The hierarchy and grouping of major sub-systems and minor sub-systems can be derived in several ways. The structure in Figure 2.2 was established after reviewing the NASA program requirements documents and the program management structure, and considering the products and services which may be developed from the Shuttle RMS program and marketed in other applications.

Some hardware sub-systems are named in more than one category. The built-in test equipment (BITE), for example, appears in Firgure 2.2 both as a sub-system of the manipulator controller interface unit (MCIU) and as a software package. This distinction reflects two separate potential products. No identification of components within each sub-system was made for this market study.

PROGRAM OUTPUTS

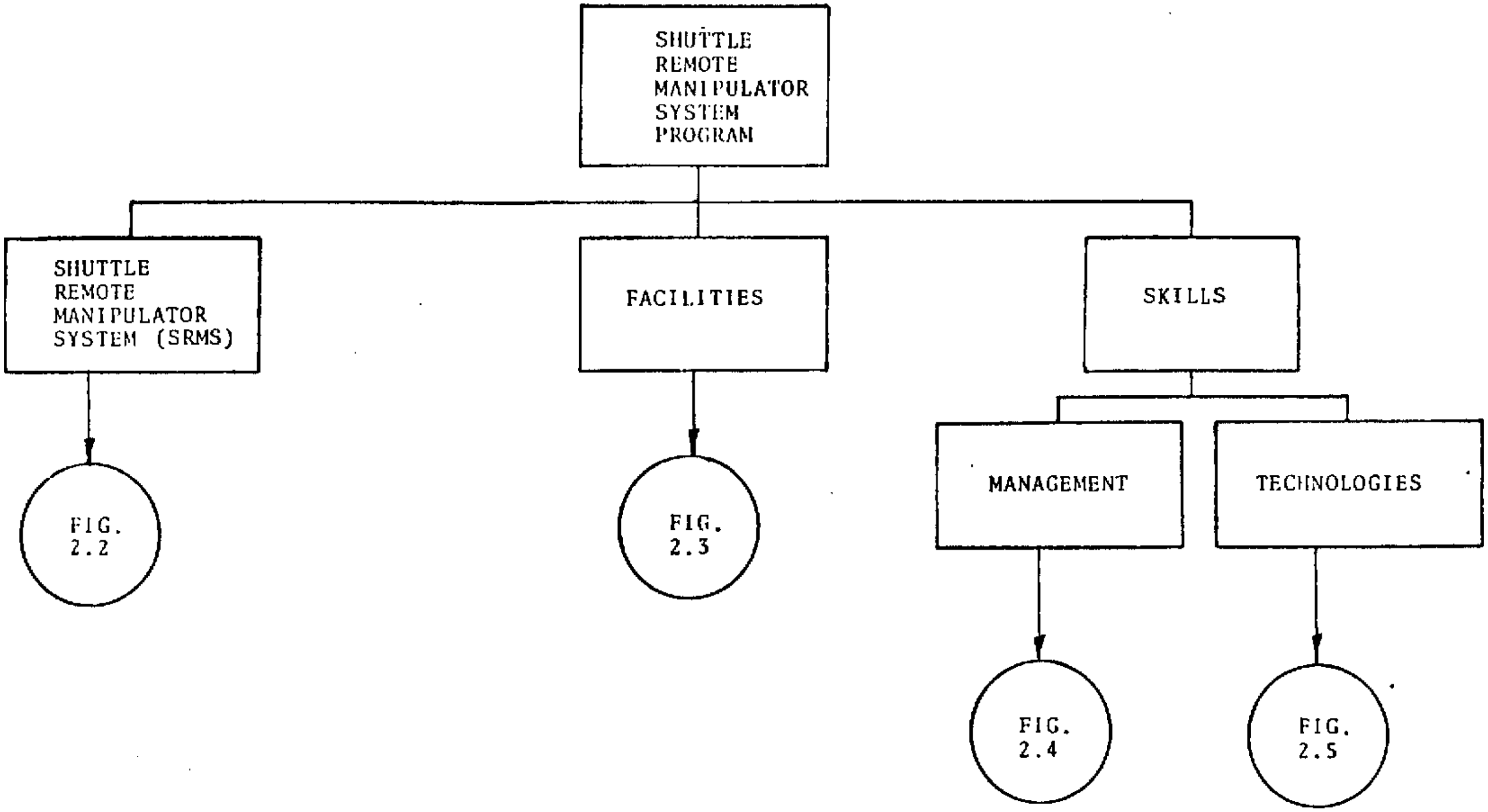

FIGURE 2.1

PROGRAM OUTPUTS - SUB-SYSTEMS

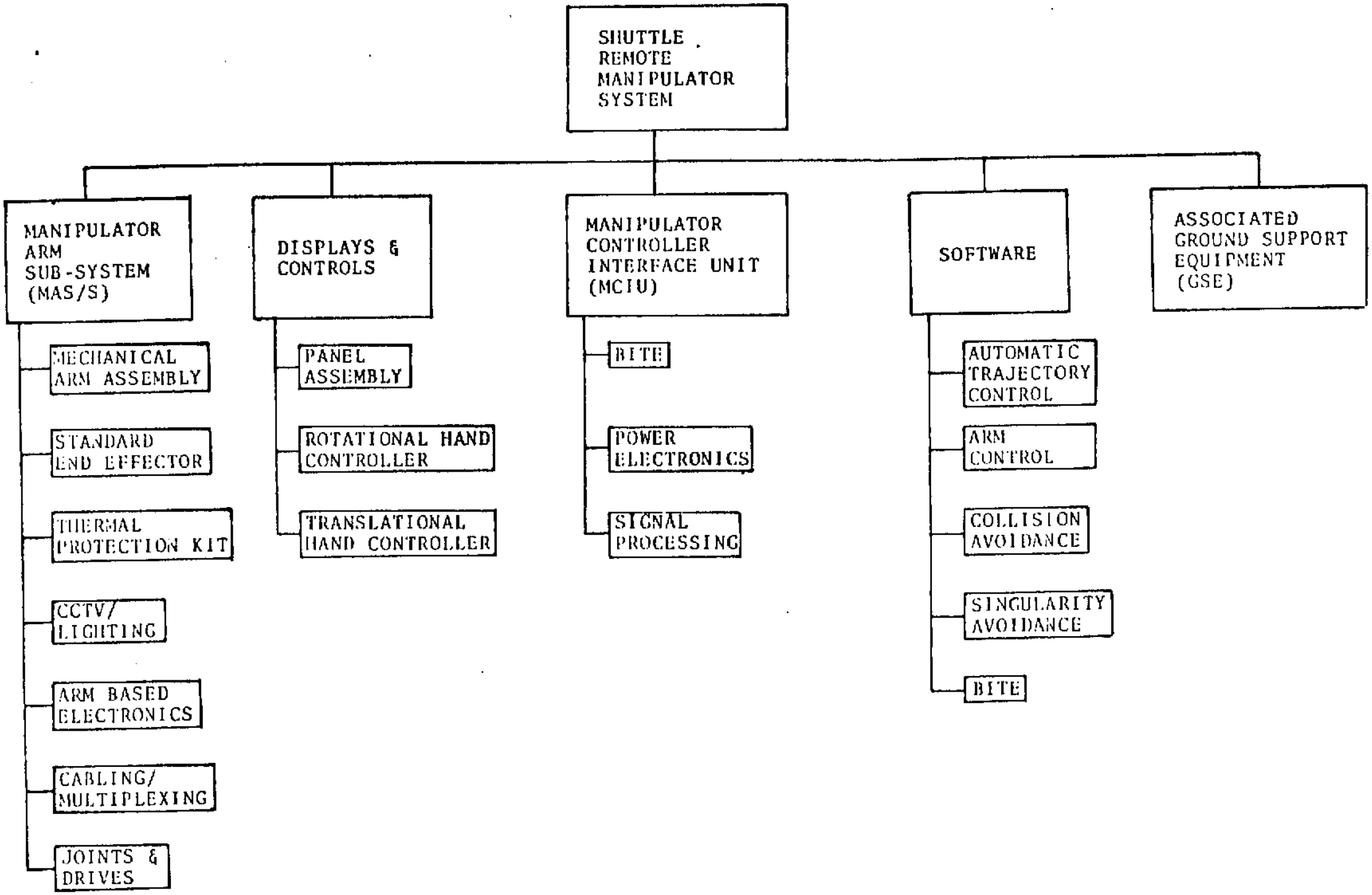

FIGURE 2.2

Facilities were grouped into four categories (Figure 2.3):

1. manufacturing
2. software and human factors development
3. integration and test
4. SIMFAC complex

The manufacturing facilities consist of several elements. Only two of the most important are shown in Figure 2.3 - precision gearing and the utilization of new materials such as carbon composites. Those facilities which are available in Canadian industry but would remain relatively unchanged because of the Shuttle RMS program are not identified in Figure 2.3. The software and human factors development facility is designed basically for software development though it also will be used for initial development of the hand controllers.

The SIMFAC complex has been designed as a versatile engineering tool to assist in the design, development and evaluation of remote manipulator systems. The SIMFAC complex consists of two separate parts - simulation and remote manipulator arm test. They can be used either in conjunction or as separate facilities. The initial applications of the simulation facility will be for the Shuttle RMS and other space applications. However, other potential applications include the simulation of remote manipulator systems for underwater, nuclear, medical, and other tasks. The facility also can be used for research and development and this application has been identified in Figure 2.3.

PROGRAM OUTPUTS - FACILITIES

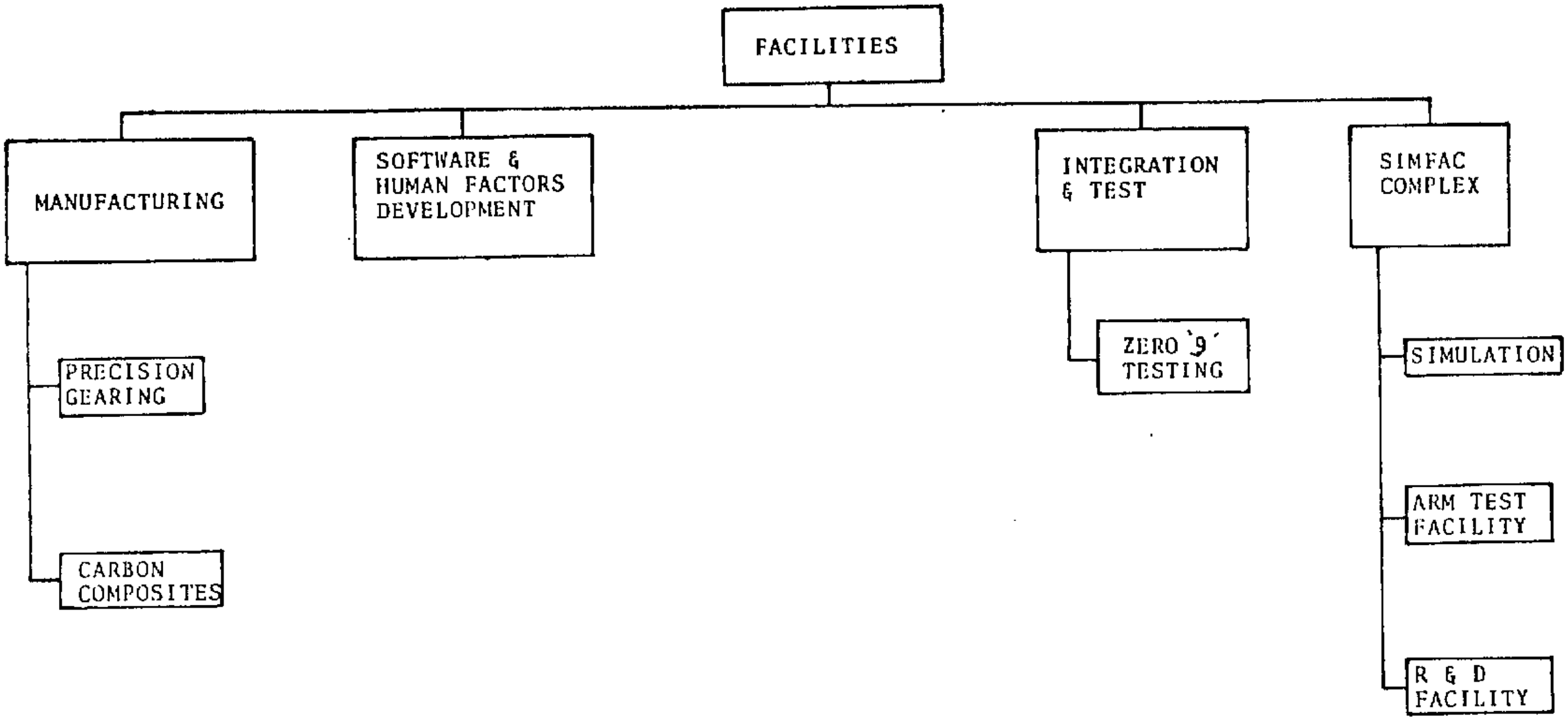

FIGURE 2.3

Management skills were divided into four categories (Figure 2.4):

1. program management
2. product assurance
3. product life cycle support
4. marketing

Program management on a major space project at the prime contractor level is one of the most important management skills which will be added to the capabilities of Canadian industry through the Shuttle RMS program. Other areas associated with the four major management skills are detailed in the hierarchy illustrated in Figure 2.4.

The final set of program outputs which were identified for this study cover the technologies which will be required for the Shuttle RMS program. A total of 14 technologies were identified. They are listed in Figure 2.5.

A summary of the major program outputs identified for this study includes:

1.	hardware	- 24 outputs
2.	facilities	- 6 outputs
3.	management	- 4 outputs
4.	technologies	- 14 outputs
	TOTAL	48 outputs

In the category "hardware", the remote manipulator, with all the associated mechanical, electrical and electronics sub-systems and components, is counted as one output. Each major sub-system and each minor sub-system is considered an output. The terms "facilities", "technologies" and management" were introduced only as titles for grouping, not to identify program outputs.

PROGRAM OUTPUTS - TECHNOLOGIES

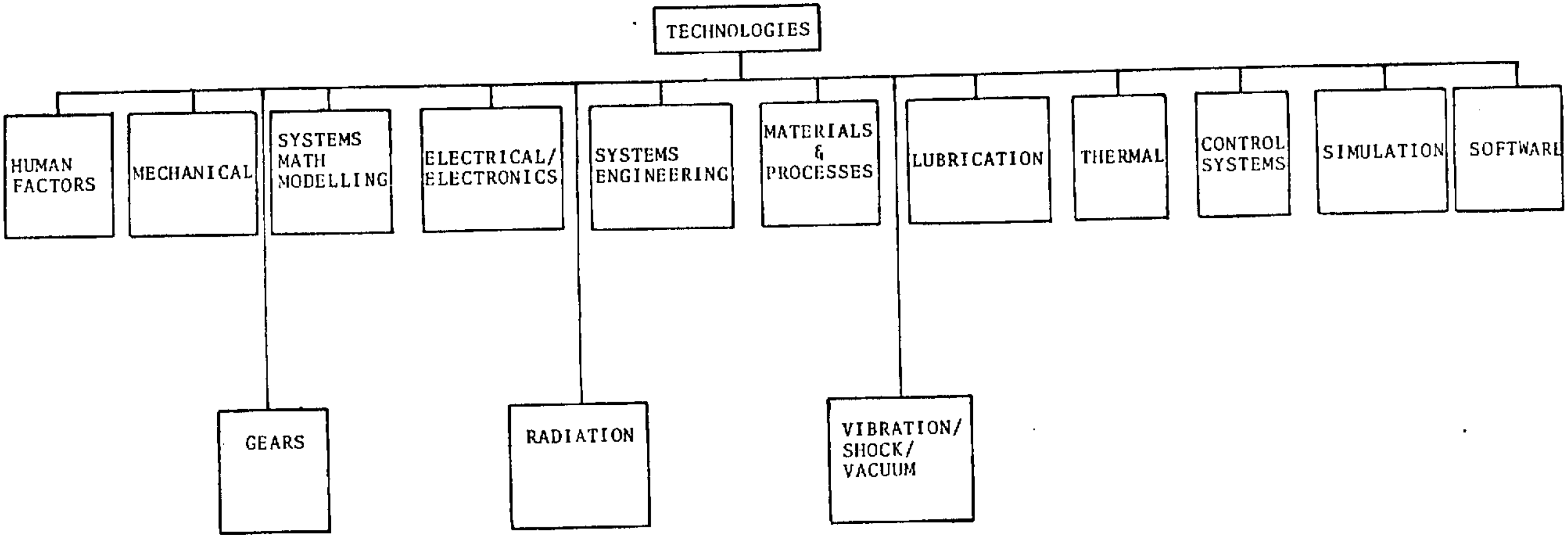

FIGURE 2.5

2.3 The Potential Applications

The reasons for considering the use of remote manipulators in a particular application can be grouped into three major categories:

1. hostile/hazardous environments
2. limited activity
3. economic/sociological considerations

Hostile or hazardous environments include conditions such as extremely high or low temperatures, or radiation or biological hazards. This category includes those conditions which prevent man from operating unless completely protected and provided with life support systems. Examples of potentially hostile, or hazardous, environments, though by no means an exhaustive listing, are provided in Figure 2.6.

Man's ability to work with extremely close tolerances, or to repeat a set of movements over an extended period of time, is limited. Remote manipulators, or, more accurately, limited sequence manipulators, can be used to do these operations. They can be programmed to complete the same task over and over again. They can be used to follow, on a miniature scale, the actions of the human control. In this respect, they have a potential in micro-surgery. Prosthetics, or artifical limbs, and man amplifiers are other examples of the application of remote manipulator technology. A list of limiting conditions in which remote manipulators have possible application is contained in Figure 2.7.

Cost of labour and even the lack of some skills are economic conditions advanced for the consideration of the introduction of industrial robots in Norway, Sweden and Japan. Industrial jobs, such as paint spraying, welding, simple repetitive operations, tasks where there are excessive temperatures, noise, or inadequate lighting are examples of sociological conditions which could lead to the application of remote manipulators, limited sequence manipulators, or robots. These and other examples of economic and sociological conditons are listed in Figure 2.8.

FIGURE 2.6

EXAMPLES OF HOSTILE OR HAZARDOUS ENVIRONMENTS

- TEMPERATURE
- PRESSURE
- RADIATION
- BIOLOGICAL
- ATMOSPHERIC
- TOXICITY
- ACOUSTICAL
- ACCELERATION/SPEED

FIGURE 2.7

EXAMPLES OF LIMITING CONDITIONS

- PROSTHETICS
- ACCESSIBILITY
- COMPLEXITY
- WEIGHT
- PRECISION (TOLERANCE)
- POTENTIAL DANGER (EG. EXPLOSION)

FIGURE 2.8

EXAMPLES OF ECONOMIC/SOCIOLOGICAL CONDITIONS

- COST OF LABOUR
- ENDURANCE
- REPETITION
- WORKING CONDITIONS
  - light
  - temperature
  - cleanliness
  - job satisfaction
  - noise (acoustical)

Identifying conditions in each of the three categories (hostile or hazardous environments, limited activity, and economic or sociological conditions) suggests possible applications of remote manipulator technology. Some of these applications are listed in Figure 2.9. All represent a potential application of either hardware, skills, or facilities from the Shuttle RMS program. However, some can be adapted more easily, and therefore have greater potential, than other applications which would require extensive modifications or development.

FIGURE 2.9

APPLICATIONS OF REMOTE MANIPULATOR TECHNOLOGY

SPACE

- UNMANNED
  - sampling
  - placement of experimental packages

- MANNED
  - payload deployment
  - module exchange
  - inspection
  - data retrieval
  - in-orbit service
  - emergency
  - placement & retrieval of experimental packages (orbiting space laboratory)
  - orbit adjustments
  - construction of space structures

UNDERWATER

- OFFSHORE OIL & GAS
- MINING
- SURVEYING & SAMPLING
- MAINTENANCE
- SEARCH & RESCUE & SALVAGE
- RESEARCH
- VESSEL MAINTENANCE

NUCLEAR

- FUELLING
- MAINTENANCE
- WASTE DISPOSAL
    - fuel
    - irradiated material
    - clothing
- INSPECTION
- ISOTOPE HANDLING

INDUSTRIAL

- MATERIAL HANDLING
- PRECISION TASKS
- REPETITIVE TASKS

RESOURCE EXTRACTION

- AGRICULTURE
    - harvesting
    - spraying
- FORESTRY
    - harvesting
- MINING
    - pit face operations

MEDICAL

- PROSTHETICS
- SURGERY

MILITARY/LAW ENFORCEMENT/ENVIRONMENTAL PROTECTION

- HANDLING
    - explosives
    - toxic materials
- RESCUE/CONTROL
    - fires
    - major disasters

TRAINING AND SIMULATION

ENTERTAINMENT

- GAMES
    - based on pick & place skills
    - simulation of activities in space

OTHER

- APPLICATION OF SUB-SYSTEMS/COMPONENTS
    - built-in test electronics
- PORTS AND HARBOURS (NORTHERN CLIMATES)
    - material handling

2.4 The Market Opportunities

The most obvious potential markets for the outputs from the Shuttle RMS program are the applications of the total manipulator system. However market opportunities also exist for the sub-systems, the skills, and the utilization of the facilities. In fact, many of the program outputs which have been identified represent potential market opportunities.

If all the systems, sub-systems, and facilities were evaluated separately for each major application, a total of 480 potential market opportunities would have to be evaluated. Each of the 480 opportunities is defined by one of the program outputs (48 were identified previously) and one of the major areas of application (10 in total). Some of the opportunities represent excellent potential markets; others are obviously marginal, or even very poor, prospects. Because 480 opportunities are too many to evaluate for this report, the analysis was limited to the potential markets for the remote manipulator system, the major sub-systems, the technologies (as a group), management skills (as a group), SIMFAC and the software and human factors development complexes, and the other facilities. This grouping represents 100 market opportunities (10 applications for each of 10 program outputs). From this group of 100 market opportunities, four were selected for detailed analysis. The selection procedure was rigorous and was conducted in the following manner.

Each of the 48 programs outputs was evaluated on the extent of the modifications which would be required to the Shuttle RMS program for each major area of application. The 48 program outputs, matched against the 10 major areas of application, produced a "modification matrix".

The 480 intersections in the matrix were graded in one of four categories:

A - no modifications required
B - minor modifications required
C - major modifications required
- not applicable, or extensive design and development changes required.

The evaluation was done by three people acting independently - the Vice-President and General Manager, and the Director of Advanced Programs of the RMS Division from Spar Aerospace, and the President of Philip A. Lapp Limited. The results from the three evaluations, which were very similar, were reviewed and a concensus established. The concensus is presented in Tables 2.1 and 2.2.

Reading along any row of the matrices and summing the grades creates a first impression of the applicability of work on the Shuttle RMS to the particular market represented by the row. For example, in the assessment of required modifications for the underwater market, the score reads 21 A's, 15 B's, 3 C's, and 3 "not applicable", or "extensive modifications required". For the industrial market, the score reads 11 A's, 14 B's, 11 C's, and 6 "not applicable" or extensive modifications required". Therefore more changes would be required to the outputs from the Shuttle RMS program in order to take advantage of opportunities in the industrial applications than would be required for the underwater market.

The results from this evaluation of required modifications were used to assess the potential market opportunities for the remote manipulator system, the major sub-systems, the skills, and the facilities (10 outputs in total). In addition to the evaluation of the modifications, other factors were taken into consideration including *a priori* judgements of the potential market size, the competition, the timing of the market

TABLE 2.1

MODIFICATION MATRIX - MINOR SUB-SYSTEMS

AREA OF APPLICATION	MANIPULATOR ARM SUB-SYSTEM							DISPLAY AND CONTROLS			MCIU			SOFTWARE				
	JOINTS & DRIVES	MECHANICAL ARM ASSEMBLY	STANDARD END EFFECTOR	THERMAL PROTECTION KIT	CCTV/ LIGHTING	ARM BASED ELECTRONICS	CABLING/ MULTIPLEXING	PANEL ASSEMBLY	ROTATIONAL HAND CONTROLLER	TRANSLATIONAL HAND CONTROLLER	BITE	POWER ELECTRONICS	SIGNAL PROCESSING	AUTOMATIC TRAJECTORY CONTROL	ARM CONTROL	COLLISION AVOIDANCE	SINGULARITY AVOIDANCE	BITE
SPACE	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
UNDERWATER	B	-	B	-	B	B	C	B	A	A	B	B	B	B	A	A	A	A
NUCLEAR	A	-	B	C	B	B	B	B	A	A	B	C	B	B	A	A	A	A
INDUSTRIAL	C	-	C	-	-	C	B	B	C	C	B	C	B	A	A	A	A	A
RESOURCE EXTRACTION	C	-	-	-	C	C	-	C	C	C	C	C	C	C	B	B	B	C
MEDICAL	C	-	-	-	-	C	C	C	B	B	C	C	C	C	A	C	B	C
MILITARY/LAW ENFORCEMENT/ ENVIRONMENTAL PROTECTION	C	-	B	-	C	C	-	C	C	C	C	C	C	C	B	B	B	C
TRAINING & SIMULATION	B	-	B	A	A	A	A	B	B	B	B	B	B	C	B	B	B	B
ENTERTAINMENT	C	-	B	-	-	C	C	B	C	C	C	B	B	-	C	B	B	C
OTHER	C	-	C	-	C	C	C	C	C	C	C	C	C	C	C	C	C	C

TABLE 2.2

MODIFICATION MATRIX - SKILLS & FACILITIES

AREA OF APPLICATION	FACILITIES						MANAGEMENT				TECHNOLOGIES													
	MANUFACTURING	HUMAN FACTORS & SOFTWARE DEV.	INTEGRATION & TEST	SIMFAC COMPLEX -SIMULATION	SIMFAC COMPLEX - ARM TEST	SIMFAC COMPLEX - R&D	PROGRAM MANAGEMENT	PRODUCT ASSURANCE	PRODUCT LIFE CYCLE SUPPORT	MARKETING	HUMAN FACTORS	MECHANICAL	SYSTEMS MATH MODELLING	ELECTRICAL/ ELECTRONICS	SYSTEMS ENGINEERING	MATERIALS & PROCESSES	LUBRICATION	VIBRATION/SHOCK VACUUM	THERMAL	RADIATION	CONTROL SYSTEMS	SIMULATION	SOFTWARE	GEARS
SPACE	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
UNDERWATER	C	A	A	A	A	A	B	B	A	B	A	B	A	A	A	A	B	B	C	-	A	A	A	A
NUCLEAR	B	B	A	A	A	A	A	A	A	B	B	A	A	A	A	A	B	C	B	A	A	A	A	B
INDUSTRIAL	B	B	A	A	A	A	C	C	B	-	B	A	B	B	B	C	C	C	-	-	A	B	B	B
RESOURCE EXTRACTION	C	B	B	B	B	B	C	C	C	C	B	B	B	B	B	C	C	C	-	-	B	C	C	B
MEDICAL	A	A	A	A	A	A	C	B	C	C	A	B	A	A	A	B	B	C	-	-	A	A	A	B
MILITARY/LAW ENFORCEMENT/ ENVIRONMENTAL PROTECTION	C	C	B	B	B	B	B	C	C	-	B	B	B	B	B	C	C	C	C	C	C	B	B	B
TRAINING & SIMULATION	A	A	A	A	A	A	B	C	C	C	A	C	A	B	B	C	-	B	-	-	A	A	A	C
ENTERTAINMENT	-	A	-	B	B	B	C	C	C	-	A	C	C	C	C	C	C	-	-	-	C	C	C	C
OTHER	C	B	C	B	B	B	C	C	C	C	B	C	B	C	C	C	C	C	-	-	B	B	B	C

and the required investment. Each market opportunity was graded by the same three people who evaluated the modifications required to the program outputs. The four possible grades were;

1 - an excellent market prospect
2 - a possible market prospect
3 - a marginal market prospect
\- - not applicable

The results of the evaluation are presented in Table 2.3.

For some applications, additional technologies to those required for the Shuttle RMS would have to be acquired. For example, problems of extreme pressure and corrosion must be addressed in underwater applications. The additional technologies which would be required for each application are identified in Table 2.3.

It should be recognized that the assessment of the market opportunities presented in Table 2.3 was developed with the viewpoint of the capabilities and interest of Spar, primarily, and the consortium members. Opportunities graded with a "2", or a "3", may be graded higher when assessed from the point of view of another Canadian company.

There are 100 market opportunities graded in Table 2.3. It is not possible to subject all of them to a rigorous analysis. From this group, four were selected, all applications of a complete remote manipulator system. The applications selected were in space, underwater, nuclear, and industrial markets. They are identified by an asterisk in Table 2.3.

TABLE 2.3

OPPORTUNITY MATRIX

AREA OF APPLICATION	NOTES: REQUIRED MODIFICATIONS AND ADDITIONAL TECHNOLOGIES	SKILLS & FACILITIES				MAJOR SUB-SYSTEMS					
		FACILITIES									
		SIMFAC & HUMAN FACTORS	OTHER	MANAGEMENT	TECHNOLOGIES	MANIPULATOR ARM SUB-SYSTEM	DISPLAYS & CONTROLS	MANIPULATOR CONTROLLER INTERFACE UNIT	SOFTWARE	GROUND SUPPORT EQUIPMENT	REMOTE MANIPULATOR SYSTEM
SPACE	NOT RELEVANT	1	1	1	1	1	1	1	1	1	1*
UNDERWATER	extreme pressures; corrosion; visibility	1	2	2	1	2	1	2	1	-	1*
NUCLEAR	nuclear engineering; irradiation	1	2	1	1	2	1	2	1	-	1*
INDUSTRIAL		1	2	3	2	3	3	2	1	-	2*
RESOURCE EXTRACTION	—	2	2	3	2	-	3	3	2	-	3
MEDICAL	medical engineering	1	1	3	1	-	2	3	2	-	2
MILITARY/LAW ENFORCEMENT/ ENVIRONMENTAL PROTECTION	—	2	3	3	2	3	3	3	2	-	3
TRAINING & SIMULTATION	—	1	1	3	2	2	2	2	2	-	2
ENTERTAINMENT	—	2	3	3	3	3	3	2	3	-	3
OTHER	—	2	3	3	3	3	3	3	3	-	3

3.0 THE SPACE MARKET

Prior to 1976, only two or three space programs required remote manipulator systems. None of the programs scheduled between 1976 and 1980 will be equipped with a remote manipulator system. However, recent NASA forecasts list approximately 40 or 50 programs between 1980 and 1990 which will require a remote manipulator system (30 is indicated as the 'realistic' estimate). The use of remote manipulators on these programs can be classified by the following major areas of application.

1. satellite deployment and retrieval.
2. in-orbit inspection, repair, and overhaul.
3. attachment of propulsion systems to change the energy levels of orbiting systems.
4. assembly of large structures in space.
5. surface sampling.

A select task group commissioned by NASA to prepare a forecast of the technology which will be required between 1980 and 2000, reported in 1976 that "the number of space application plans for teleoperators, as indicated by the number of established study or development programs and proposals has nearly tripled during the last 8 to 10 years". 1/

The NASA technology forecast also discussed the general evolution of remote manipulator systems. Recognizing that a significant degree of human control is presently required, recent research and development efforts have been directed toward systems capable of dealing with various environments and to interact with humans at a very high level. In the next five years, developments will be directed to improving "manipulation and locomotion in relatively realistic and complex environments". 1/

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1. "A Forecast of Space Technology 1980-2000", National Aeronautics and Space Administration, Washington, D.C., 1976.

One of the most important developments in the 1980's is expected to be in the sensory functions. Scene data may be collected, processed, and analyzed in milliseconds. This development should be accompanied by advances in sensory feedback. With these developments, robots could be used for planetary exploration particularly in locations such as the far side of the moon where real time, man in the loop, control is not possible.

The last ten years of the century are expected to see further developments in problem solving, learning, decision-making, sensory analysis, and other capabilities related to artificial intelligence. These will permit the operation of semi-autonomous surveys.

3.1 Market Analysis

3.1.1 Unmanned Programs

The NASA Mission Model [1] identifies 28 programs to the year 1991 which are classified as inter-planetary explorations. Within this group, nine programs require the vehicle to land, the remainder are fly-by or orbital missions. Of the nine programs which will land on the planet surface, one is already in operation (the Viking program to Mars), another has one vehicle in the program, and the remaining seven programs each have two vehicles. Two lunar explorations programs are planned for the late 1980's each having two vehicles.

Therefore, there are a total of 17 space vehicles in the NASA Mission Model which will land and which could be equipped with a remote manipulator system. The tasks which could be assigned include measurement of the chemical and isotopic composition of the surface material, collection and return of samples to Earth and geochemical and geological experiments.

Discounting the present Viking program (two vehicles), this leaves 15 vehicles which could be equipped with a manipulator system. Of these, approximately one-third may be equipped with two manipulators. There also would be a requirement for one spare manipulator at the launch site for each program (eight programs in all). It is assumed that the spares will be required by the first launch in each program. Therefore, the total requirement for remote manipulators for unmanned programs could reach 28 systems. At an assumed price of $2 million per system, including controls and interface units, this represents a market potential of $56 million for hardware.

Design and development activities could add another $10 million to each program, a total of $80 million. This would include only redesign of the baseline system to meet the specific requirements of any one mission.

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1. Prepared in 1973 and reviewed annually for accuracy.

3.1.2. Manned Programs

In 1974, NASA commissioned a study "to define a set of strong applications of a remote manned system and analyze the operational requirements and development issues of these applications".[1/] The applications were divided into four categories: the Shuttle, Space Tug, Spacelab, and detached payloads. The primary functions of the remote manipulator system in these programs will be module exchange, inspection, overhaul and maintenance, and satellite systems stabilization.

Contracts have been awarded to North American Rockwell for two Orbiter space Shuttle vehicles. The launch of the first vehicle is expected in 1980; the second in 1981. NASA is seeking Congressional approval in the 1978 budget to proceed with the long lead procurement necessary to convert the atmospheric flight test vehicle (the Enterprise) to become the third orbital craft.

NASA and the Department of Defence (DOD) are negotiating to determine who will receive the supplementary budgets of approximately $1 billion which will be required to start the long lead procurement and construction of the fourth and fifth Shuttle vehicles. This complement of five vehicles should satisfy the requirements for U.S. launches through the 1980-1990 decade.

Each shuttle Orbiter will be equipped with one remote manipulator system (SRMS). With one spare SRMS, and a unit price of $15 million, this represents a potential market of $90 million. For the market model, it is assumed that $15 million will develop before 1980 and the remaining $75 million between 1981 and 1985.

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1. "Shuttle Remote Manned Systems Requirements Analysis", 3 volumes, Martin Marietta Corporation, Colorado, February 1974.

The Space Tug program has been proposed to allow refurbishment of hardware in synchronous orbit (cf. low earth orbit satellites). The objectives of the Space Tug program are to place satellites in high energy orbits, to move satellites from one orbit to another, and, in later sorties, to perform maintenance either by in situ module replacement, returning the payload to the Shuttle for repair, or returning it to earth if necessary. In this role, it often has been referred to as a "free flying teleoperator". Some of the Space Tugs will be equipped with both a remote manipulator system and a spares package. On these Tugs, there would be a telecommunications link between the Tug and either a Shuttle or Earth-based controller.

The NASA Mission Model projects the requirement for a total of 35 Space Tugs from 1981 to 1991, including an allowance for a one percent risk of not recovering the Tug on any one flight. Of the 35 Tugs, 12 are initial performance Tugs which could be expended, seven are to be full performance Tugs, and 16 are kick-stage Tugs to be used to minimize expending Tugs for planetary missions. For the market model, it is assumed that the kick-stage Tugs will not carry manipulator systems, since their primary function is to place equipment in specified orbits. It is assumed that the remote manipulator systems on the initial and full performance tugs will be similar to the Shuttle RMS, though perhaps not as complex. At an approximate price of $8 million per unit, this would represent a market of $152 million for hardware ($136.0 million in 1981-1985 and $16.0 million after 1990). The design and development phase could add another $15 million.

Several programs have been incorporated into the NASA Payload model which will depend on the availability of an orbiting space laboratory. These programs include research and development on materials science technology in a weightless environment, traffic management techniques, earth and ocean dynamics experiments, and multidisciplinary experiments in stellar astronomy, high energy physics and remote sensing of the Earth's resources and environment. More than 336 missions scheduled between 1980 and 1991 will require the use of an orbiting laboratory. To accommodate these missions, a total of 5 support modules are planned. They are to built by the European space community, represented by ESA, the European Space Agency.

For the market model, it is assumed that each module of the Spacelab program will be equipped with a manipulator system similar to that on the Shuttle RMS but without the complete capability.

At a price of $10 million per unit, the mainipulator requirements for the Spacelab program would generate a market of $50 million. The design and development for this phase could add another $5 million.

The final set of payloads in the NASA Mission Model are the so-called free flying experiments such as the Space Telescope (ST) and the Long Duration Exposure Facility (LDEF). It is assumed that initial orbit, repair, and refurbishment of these experiments will be carried out using either an Orbiter vehicle or a Space Tug and that remote manipulator systems designed and built specifically for these experiments will not be required.

Other facilities and equipment will be required to support the SRMS hardware on the Shuttle, Space Tug, and Space Laboratory programs. These requirements could include ground support equipment, repair and overhaul capabilities, training facilities, modifications to original equipment, and study contracts. The program specifications for the Shuttle require that any payload must be removable from an Orbiter within a four hour period. Preliminary studies indicate that a manipulator system will be required to perform this task. Assuming that a system would be priced at $25 million, that special fixtures would be required to suit various payloads at a price of $5 million per set of fixtures, and that one system with an accompanying set of fixtures would be required at each launch site (Kennedy Space Center and Vandenberg), the market for ground support equipment could reach

$60 million. This market is assumed to be averaged over the five year period 1981 to 1985.

It is assumed that there will be a market of $1 million per year to provide repair and overhaul capabilities to service the Shuttle missions. Training facilities also will be required. Some of the hardware items which will be required could be purchased in Canada. By 1980, total sales could reach $4 million.

The Shuttle and its associated hardware will follow a standard design. A user will be required to adapt the payload to meet the Shuttle vehicle specifications. However, some modifications may be expected at the interfaces, such as the end effectors of the Shuttle RMS. Users may request special end effectors or payload handling devices. Spar has already received requests about the specifications of the RMS and what modifications may be possible. It is estimated that a market for modifications of $1 million per year could develop after 1980.

Study contracts, similar to the present preliminary design and development phase of the Shuttle RMS program, could add another segment to the market. It is assumed that the market for these study contracts could average $10 million in each five year period to the end of the century.

3.1.3 Shuttle Special Purpose Manipulator System (SPMS)

One of the main objectives of the space Shuttle program is the on-orbit servicing of satellites and other payloads. Rendezvous is made with the satellite. The satellite is captured using the Shuttle RMS and transferred to the payload bay. Once it is locked in position, the satellite can be inspected. If repairs are necessary, and possible at that time, the work will be done using the Shuttle Special Purpose Manipulator System (SPMS).

The Goddard Space Flight Center, the agency responsible for the development of the Shuttle SPMS, already has identified 10 programs which could benefit from an on-orbit inspection, repair, and overhaul capability. The 10 programs are identified by the following acronyms:

1. MMS Structure
2. LANDSAT
3. EXPLORER
4. BESS
5. EOS
6. EGRET
7. SSOS
8. HEAO
9. GEOS
10. TIROS

Present plans project the launch of the MMS Structure on a Shuttle orbiter flight in February, 1980. If the resupply capability is determined to be feasible based on this program, and the LANDSAT, EXPLORER, and BESS programs, a decision is expected requiring the following programs to have resupply capability.

Cost estimates for the design and development of the manipulator system for the MMS Structure program, the first to have the resupply capability, run to $15 million. This will provide a proto-flight. For reasons of weight and economy, the capabilities of the first manipulator system will be limited to those functions which are required to demonstrate the viability of the resupply concept. The proto-flight will not have a life capability. Therefore, if the resupply concept appears to be viable, redesign and additional hardware will be required for future programs. The cost of these design changes has been estimated at approximately 50 percent of the original program, or $7 million, including additional hardware, a total design and development cost of $22.0 million.

Assuming that each of the five Orbiters carries one SPMS, with one spare at each launch faility, a price of $7 million per unit would produce a market of $49 million, $14 million in 1976-1980 and the remaining $35 million in the period 1981-1985.

The second LANDSAT program is scheduled to commence in 1979 together with the first in the EXPLORER series. By this time a market for spares should begin to develop. This market is estimated at $1 million per year. Special terminal devices and further changes to the basic manipulator system could add another $1 million a year to the market.

After 1980, improvements to the SPMS can be expected. Some of these improvements could include extended reach, increased angular travel, more precise positioning, improved displays, and increasing semi-automatic or automatic control. These improvements would be made continually and therefore a market of $3 million annually, commencing in 1981, is assumed for all design and development efforts and resulting hardware.

The SPMS to be used on the first series of resupply programs represents a first generation. It is expected that at some time in the future, the year 1986 was selected for this report, the complete system will be upgraded to incorporate new concepts and advances in manipulator technology. The design and development cost for this second generation is estimated at $30 million over the five year planning period 1986-1990. Sales of the advanced units, following the design and development phase, are difficult to estimate. For this study, it is assumed that sales of an advanced generation of SPMS will not be made before 1990.

As DOD becomes a regular user of the space Shuttle and the transition is made from conventional launch vehicles at the Vandenberg facility to the Shuttle system, a new market for manipulator systems could develop. Some of the basic requirements of DOD missions are;

1. a sun synchronous (polar) orbit.
2. DOD observer missions of short duration (less than 90 days); recovery of some portions of the spacecraft (cassettes, recordings, films, etc.) is a requirement for these missions.
3. immediate replacement of the "observer spacecraft".

Based on these requirements, on-orbit replacement and repair capabilities would appear to be an attractive feature. At the DOD Space Test Program, Space Shuttle Utilization Conference, held in Washington in August 1976, it was stated that DOD will have the primary payload on 30 percent of all Shuttle flights or about 20 flights a year. With one flight every two and one-half weeks, it is probable that DOD could justify a dedicated SPMS. The dedicated SPMS would be designed to mate specifically with DOD payloads. This could result in an additional design and development program, estimated at $15 million in the 1976-1980 time frame, and the purchase of hardware to be located at Vandenberg and Kennedy, estimated at $28 million for four systems to be purchased between 1981 and 1985.

The final potential market opportunity on SPMS would involve personnel and equipment support at the launch sites. It is estimated that this market will increase from a base of $500,000 a year in the planning period 1981-1985 to $1 million per year by 1986-1990.

A summary of the projected market in each of the activities discussed in this section is presented in Table 3.1. The market in the period to 1980 consists mainly of study contracts and design and development work. The major hardware items are covered in the five year period 1981 to 1985, a total market of over $400 million. The second major

TABLE 3.1 (Page 1 of 2)

SUMMARY OF THE PROJECTED SPACE MARKET FOR RMS AND SPMS (1976-1990)

PROGRAM	PROJECTED MARKET ($ millions) 1976 - 1980	1981 - 1985	1986 - 1990
SHUTTLE RMS			
UNMANNED			
- hardware	$ 4.0	$ 22.0	$ 30.0
- design & development	10.0	20.0	50.0
Subtotal	$14.0	$42.0	$80.0
SHUTTLE RMS			
MANNED			
- Orbiter	$ 15.0	$ 75.0	$ 0.0
- Space Tug design & development	15.0	0.0	0.0
- hardware	0.0	136.0	0.0
- spacelab	25.0	10.0	20.0
- Ground Support Equipment	0.0	60.0	0.0
- Repair and overhaul	5.0	5.0	5.0
- Training facilities	4.0	0.0	0.0
- Modifications	0.0	5.0	5.0
- Studies	10.0	10.0	10.0
Subtotal	$74.0	$301.0	$40.0

TABLE 3.1 (Page 2 of 2)

SUMMARY OF THE PROJECTED SPACE MARKET FOR RMS AND SPMS (1976-1990)

PROGRAM	PROJECTED MARKET ($ millions) 1976 - 1980	1981 - 1985	1986 - 1990
SPMS			
- Design & development	$ 22.0	$ 0.0	$ 0.0
- Hardware	14.0	35.0	0.0
- Spares	5.0	5.0	5.0
- Special Devices	5.0	5.0	5.0
- Improvements	0.0	15.0	15.0
- Redesign	0.0	0.0	30.0
- Hardware (advanced system)	0.0	0.0	0.0
- Redesign (DOD)	15.0	0.0	0.0
- Hardware (DOD)	0.0	28.0	0.0
- Support (Personnel)	0.0	2.5	5.0
Subtotal	$61.0	$90.5	$60.0
TOTAL	$149.0	$433.5	$180.0
ADJUSTED TOTAL*	$149.0	$279.0	$334.5

* projected markets in 1981-1985 and 1986-1990 adjusted so that the total market for 1981-1990 remains the same but the projected market in 1986-1990 exceeds the projected market in 1981-1985 by 20%.

contracts in proportion to the donations, or fees, made by the member nations.

The most important factor influencing market penetration is the competition. The number of suppliers, the length of time in business in a particular market, and their investment are important elements in the estimation of market penetration.

Because of agreements respecting the development of a remote manipulator system for the space Shuttle, there is in effect no competition for the hardware on the first series of purchases. Obviously the company which is involved in this phase of the program will be in a position of maximum advantage for future purchases, and for related programs such as the planned orbiting space laboratory.

However, for the programs requiring a new design, such as the unmanned landing programs on the Moon and on Mars and the space Tugs, the competition will be increased. Companies presently supplying hardware to the nuclear industry and perhaps the underwater market could become involved. The fact that the Canadian consortium has the experience in producing hardware for other space programs, coupled with the experience to be gained on the space Shuttle RMS program, should place those Canadian companies in an excellent position to obtain sales in other segments of the space market.

3.3 Potential Market Penetration

In the space market, the consortium can be expected to achieve a significant share of the Orbiter, Space Tug, and Spacelab markets, including associated hardware and services, in the early years of the programs. In later years, when competion develops, the market share should decrease. For this study, it is assumed that the market share will be 80 percent through the first five year planning period, 1976-1980, and then will decrease by 10 percent per quinquennial to a level of 60 percent by 1986-1990.

The market share of the unmanned programs is expected to be much less from the start of the planning period since competition already exists from those companies which supplied hardware for the Surveyor and Viking series of unmanned landers. Therefore, for this analysis, a market penetration of 30 percent in all planning periods is assumed.

The final definition of the SPMS program still remains to be made. However, preliminary discussions seem to indicate that the Canadian consortium assembled for the Shuttle RMS program will be in an excellent position to acquire a major portion of the SPMS contracts. For this study, it is assumed that the market penetration for the SPMS hardware and services will be similar to that on the Shuttle RMS program - 80 percent in 1976-80 decreasing by 10 percent in each quinquennial to 60 percent in 1986-1990.

3.4 The Potential Market (Space) and a Comparison with the Previous (1974) Trend Analysis

The estimates of market penetration which are summarized in Table 3.2 generate a projected cumulative market for remote manipulator systems in space applications of $466.0 million to 1990 (Table 3.3).

The projected market exceeds an earlier projection made in 1974 for Spar by P. A. Lapp Limited by approximately 100 percent. The two projections are compared in Figure 3.1. The major reason for the increase in the projected market is the addition of more than $200 million in design and development contracts. Other contributing factors include an increase in the estimated unit price of a remote manipulator system for the Orbiter, from $6 million per unit to $15 million, the projected sales of special terminal devices on SPMS, the projected sales of SPMS to DOD, and the provision of training facilities and support personnel.

TABLE 3.2

ESTIMATED PENETRATION OF THE SPACE MARKET BY CANADIAN INDUSTRY FOR SALES OF REMOTE MANIPULATOR SYSTEMS

MARKET APPLICATION	MARKET PENETRATION (%)		
	1976-1980	1981-1985	1986-1990
SPACE - Unmanned Programs	30	30	30
- Shuttle Manned Programs	80	70	60
- SPMS	80	70	60

TABLE 3.3

PROJECTED SALES OF REMOTE MANIPULATOR SYSTEMS IN THE SPACE MARKET BY CANADIAN INDUSTRY[1]

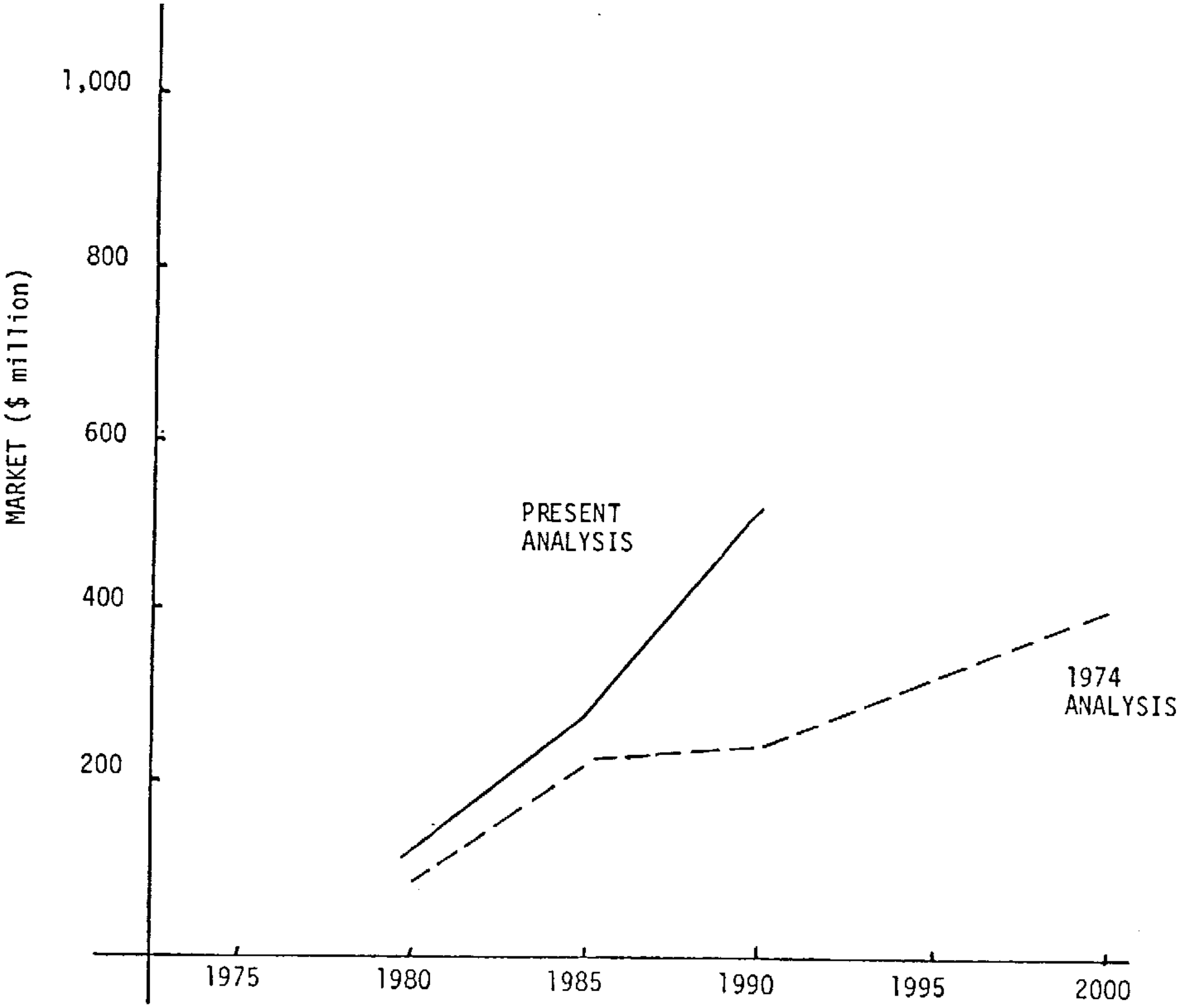
MARKET APPLICATION	PROJECTED SALES ($ millions)		
	1976-1980	1981-1985	1986-1990
SPACE - Unmanned Programs	$ 4.2	$ 16.6*	$ 20.0*
- Shuttle Manned Programs	59.2	108.5*	111.5*
- SPMS	48.8	48.8*	49.2*
TOTAL	$112.2	$173.1	$180.7

1. derived from applying estimated market penetration factors in Table 3.2 to projections of the total space market in Table 3.1.

* based on adjusted projected markets (see Table 3.1).

FIGURE 3.1

PROJECTED CUMULATIVE SALES OF REMOTE MANIPULATOR SYSTEMS IN THE SPACE MARKET BY CANADIAN INDUSTRY - A COMPARISON OF TREND ANALYSES



4.0 THE UNDERWATER MARKET

During the 1960's considerable interest was directed to the oceans - the "inner space". The aerospace industry responded to this interest with the construction in 1964 of the ALUMINAULT by Reynolds International and General Dynamics, and the ALVIN by Litton Industries, the construction of the BEN FRANKLIN by Grumman and the DEEP QUEST by Lockheed Missiles and Space Company in 1967, and the BEAVER MARK IV by North American Rockwell in 1968. With the exception of the BEAVER MARK IV, all were designed to operate at great depths, ranging from 8,000 to 15,000 feet. These exceptional capabilities were purchased at great cost. When spending on ocean research was reduced, interest in the submersible as a research vehicle declined dramatically.

Even though the market suffered setbacks during the 1960's, it was punctuated by some remarkable events:

- In 1963, the United States lost the submarine Thresher and all crew. This tragic loss led directly to the development of the first submersible specifically designed for undersea rescue. Built by Lockheed, the DSRV-1 (Deep Sea Rescue Vehicle) is nuclear powered and can be transported either by C-141 or piggyback on a submarine.
- In 1966, the United States lost a hydrogen bomb off the coast of Spain. The bomb was eventually recovered from 868m using a cable-controlled submersible, CURV (Cable-controlled Underwater Recovery Vehicle), equipped with high resolution sonar, two television cameras, and a crude manipulator device.
- In 1969, ALUMINAUT participated in the salvage and raising of the ALVIN which had been lost in 1968.
- In 1973, another CURV assisted in the rescue of PISCES III, down in 1,575 feet of water off southern Ireland.

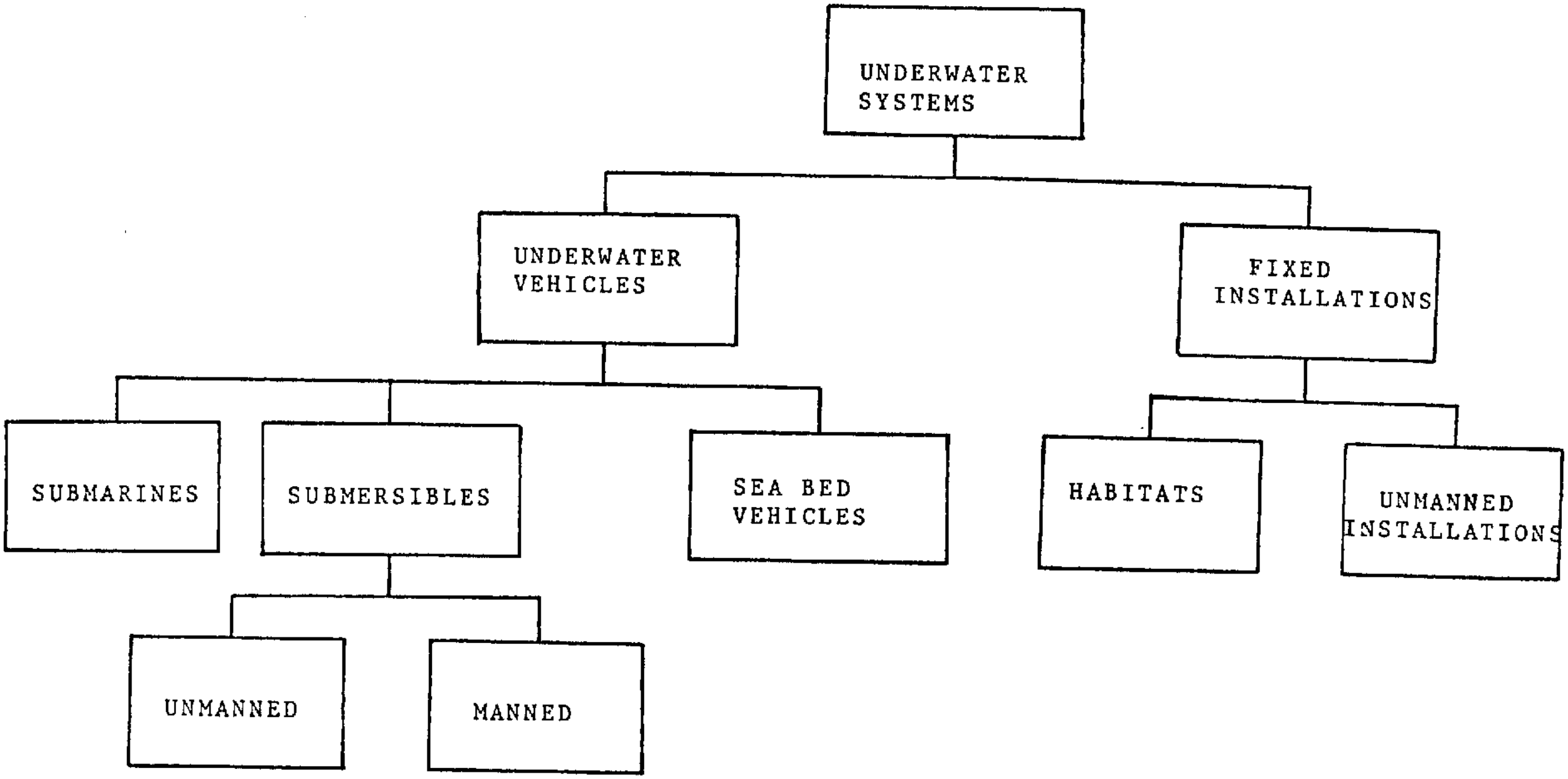
In the early 1970's, the demand for underwater vehicles began to rise, mainly due to an increase in offshore oil and gas activities. Five submersibles were operating in the North Sea in 1973. Twelve were operating in the area in 1975 and another five or six were reported to be on stand-by. To-day submersibles are less sophisticated, designed to work at much shallower depths (usually between 1,000 and 2,000 feet) and less expensive than earlier submersibles of the ALUMINAUT or BEAVER class.

The ALUMINAUT was designed to carry a crew of two or three, plus three to four observers, and to operate at depths up to 15,000 feet. The capital cost was reported to be $4 million. The ARCHIMEDE, a French submersible of the same generation, was designed to operate at depths up to 36,000 feet with a crew of three. The cost was in excess of $4 million. In comparison, the PC-14, one of the latest Perry submersibles, was designed to operate at depths to 1,200 feet with crew of two. The cost is approximately $120,000. An upper limit on cost for this new generation of submersibles is represented by those with diver lock-out capability where the price may reach $1 million, or slightly more.

To-day there are many types of underwater systems including manned and unmanned submersibles, tethered vehicles, and habitats. For this report, we have adopted the classification illustrated in Figure 4.1.

FIGURE 4.1

CLASSIFICATION OF UNDERWATER SYSTEMS



If the name or designation of the submersible has changed, the changes are recorded together with the original name. The inventory excludes all "wet submersibles", that is submersibles which are used mainly to transport divers and which have no airtight cabin or compartment.

The results of three market analyses of remote manipulator systems for underwater applications are presented in this study. The first was developed at M.I.T. and presented as a working draft to a collegium held in February, 1976. The second analysis was completed in April 1976 by ERNO Raumfahrttechnik GmbH, West Germany. The third analysis was prepared by the writer.

4.1.1. The M.I.T. Analysis

The M.I.T. analysis is based on an inventory (1975) of 96 manned submersibles, over half of which are equipped with manipulator systems.[1/] In addition, it was estimated that there are 10 to 20 remotely manned underwater inspection systems which are potential applications for remote manipulators.

It was estimated that the market for new remote manipulator systems would grow at a rate of about 20 percent per year based on the cumulative need associated with;

1. the on-going maintenance and inspection of existing platforms, pipelines, and communication systems.
2. continued offshore exploration and new production.
3. retrofit to existing submersibles

Based on this estimated growth rate, the market for remote manipulators was projected at 30 units per year, plus or minus 30 percent. Though not stated explicitly in the analysis, the projection of 30 units per year can be derived by applying the 20 percent growth rate to the

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1. Compared with the inventory in Appendix A which lists 115 submersibles of which 29 are under construction or in the design stage.

total of two-thirds of the existing inventory of 96 submersibles (representing the approximate number with manipulator systems) plus an estimated 15 remotely manned underwater inspection stations (total of 79), and averaging over seven years. [1/]

At a price ranging from $100,000 to $250,000 per unit, the sales from a projected market of 30 units per year (± 30%) would average between $2,000,000 and $10,000,000 per year. [2/]

4.1.2 The ERNO Analysis

The ERNO market analysis was based on activities in the North Sea area. The first segment of the analysis covered general offshore work and scientific activities; the second segment covered systems associated with specific equipment such as drilling rigs and pipe laying barges for the offshore oil and gas industry. The analyses are based on the premise that the market for remote manipulators will be a function of the development expenditures for offshore oil and natural gas production.

The analysis starts from a projected inventory of 59 submersibles by the end of 1976 (cf. to 96 in the M.I.T. inventory and 125 in the inventory compiled for this study and presented in Appendix A[3/]). Of the 59, 33 are engaged in non-scientific services.

Vickers Oceanics Limited, one of the submersible operators in the North Sea, estimate that their present fleet of 12 submersibles will increase to 18 by 1980 (50% total growth) and to 24 by 1985 (33 1/3% total growth from 1980 to 1985). Since Vickers Oceanics Limited are the dominant submersible fleet operators in Europe, ERNO concluded that it is unlikely that this growth rate will be matched by other

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[1/] $79\,(1.2)^{x} - 79 = 30x$

[2/] $\$\ 2\text{ million} \approx \$100{,}000 \times (30-9)$
$\$\ 10\text{ million} \approx \$250{,}000 \times (30+9)$

[3/] The 59 submersibles may represent the number in the inventory estimated to be equipped with a remote manipulator system.

companies. Therefore, for the total submersible industry, the growth rates were reduced to 30 percent for the period from 1976 to 1980 and to 15 percent for the period from 1980 to 1985. Assuming zero growth in scientific submersibles, these growth rates generate a market for 10 new submersibles by 1980 (30% of 33) and 7 between 1980 and 1985 (15% of 43).

Many submersibles are equipped with more than one manipulator. The ERNO report assumes an average of 1.3 manipulators per submersible. Applied to the market forecast for submersibles, this generates a requirement for 13 manipulators by 1980 and another 9 manipulators between 1980 and 1985.

To these estimates ERNO adds a market for an additional 10 manipulators between 1976 and 1980 and another 33 between 1980 and 1985 for unmanned submersibles and other structures in the North Sea. This increases the total projected market for manipulators to 65 by 1985.

The ERNO analysis then proceeds to analyze projected expenditures by the offshore oil and gas industry for marine systems. These systems include pipe lay barges, mobile drilling rigs, production platforms, and other similar equipments. Market projections published in Ocean Industry indicate that, between 1975 and 1980, 45 percent of all development expenditures and 57 percent of all expenditures in construction activities for the offshore oil and gas industry will be spent by Europe. Of the total expenditures by Europe in construction, it is estimated that about $1,600 million will be for "other items" including new submersibles equipped with remote manipulator systems.

Based on these data, ERNO estimated that the number of new remote manipulator systems required for the offshore oil and gas industry (Europe) would be equivalent to 10 percent of the total number of offshore systems under construction or planned. The publication, Ocean Industry, estimates that the number of drilling rigs, production platforms, pipe lay barges, and deep water terminals under construction or planned to 1980 totals 382. Applying the 10 percent factor based on 50 percent for Europe and 20 percent for submersibles in the "other items" category generates a market forecast of 38 remote manipulators required in Europe by 1980. The study assumes that the requirement for the period 1980 to 1985 will be the same - another 38 systems.

Therefore the total requirement to the year 1984 for remote manipulator systems for the underwater market will be approximately 141 units (65 based on the first segment of the analysis and 76 based on the second). ERNO estimated that the price of each system would be 200,000 DM, on average, or about $75,000. This estimated cost per unit would produce a market of $10,575,000 over 10 years, or an average of $1,057,500 per year.

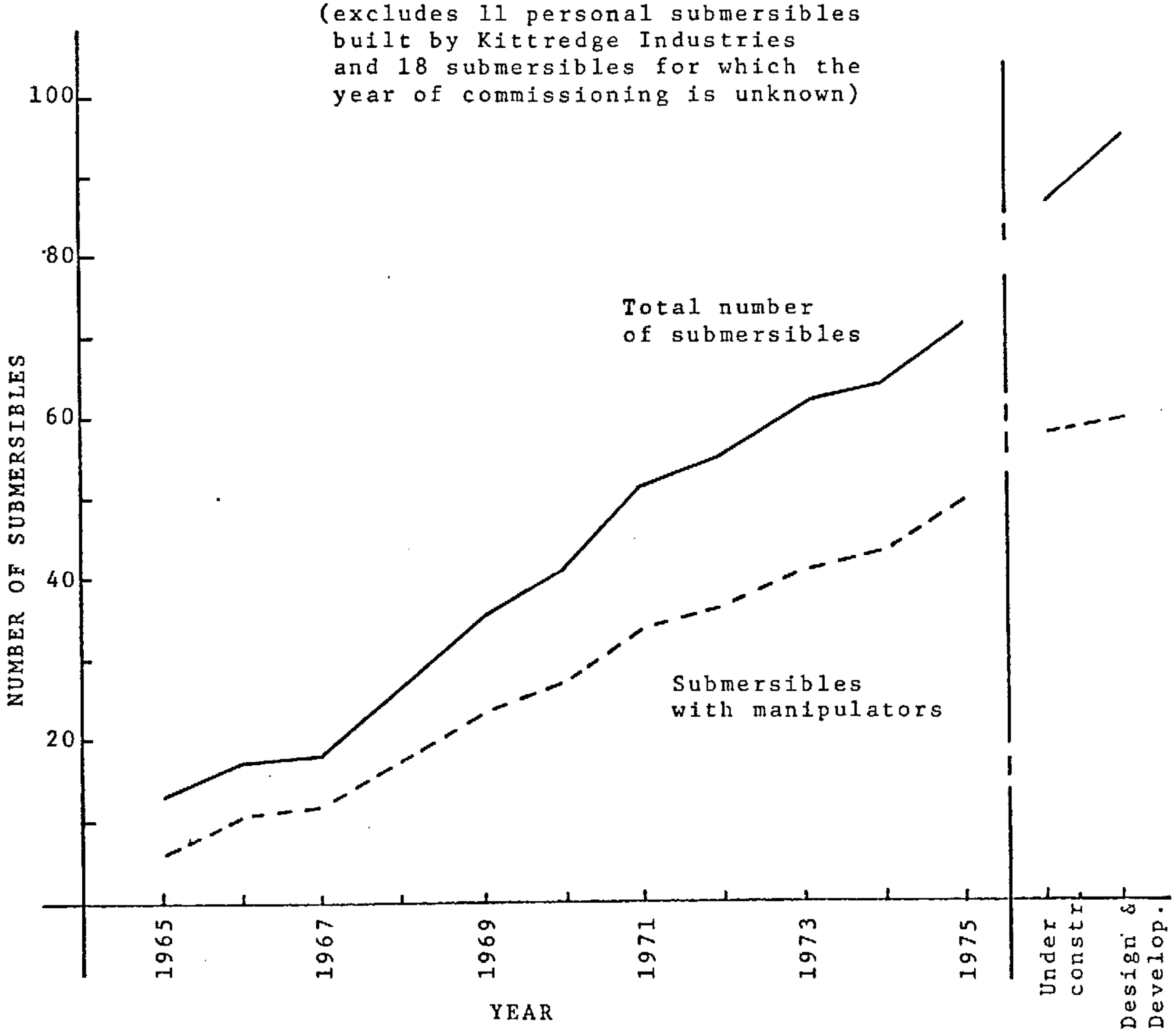
Applying the M.I.T. estimated price of $100,000 to $250,000 per unit would generate a market forecast of $1,410,000 to $3,525,000 per year.

4.1.3 P.A. Lapp Limited Analysis

Of the 130 underwater vehicles built, under construction, or in the design stage in 1975, at least 73 are equipped with remote manipulator systems (RMS). Another 38 may have a manipulator system; 19 do not have a RMS. Only 12 vehicles were operating in 1965; and eight of these were equipped with manipulators. Therefore construction of underwater vehicles has been growing at an average of 24 percent per year over the last ten years. A graph illustrating this growth is presented in Figure 4.2.

FIGURE 4.2

NUMBER OF MANNED SUBMERSIBLES IN OPERATION



The graph is cumulative and shows the total number of underwater vehicles in operation each year from 1965 to 1975. Two data points after 1975 add the number of underwater vehicles under construction and the number at the design and development stage. The date of construction for 21 underwater vehicles is unknown and therefore they are excluded from Figure 4.2. In addition, 11 submersibles built by Kittredge Industries for recreational use are excluded.

The range of tasks which can be performed by submersibles is demonstrated by entries in the logs of the NEKTON series of submersibles (NEKTON ALPHA, NEKTON BETA, and NEKTON GAMMA). These submersibles, built between 1968 and 1971, carry one crew member and one observer, have between 17 and 20 viewports, are pressure tested to 1,500 feet, carry sonar, television with videotape, and a remote manipulator system. They have been tendered using everything from a 151 foot supply ship to a 16 foot runabout. The submersibles can be leased for $1,000 per day including crew.

Since 1968, these submersibles have completed over 1,250 dives. Inspections, monitoring, geological explorations, biological studies, and search and salvage missions were the objectives on many of these dives. Ocean outfalls, petroleum drilling and production platforms, seafloor wellheads, and pipelines were inspected for proper emplacement, structural integrity, corrosion effects, scour occurrence, unsupported span lengths, and proper operation. Monitoring tasks included supervision of underwater operations by non-divers and detection of the source of oil leaks off Santa Barbara, California.

The submersibles also have assisted in _in situ_ sampling by geologists and biologists rather than relying on divers or random sampling. Submersibles are ideal platforms for biologists because they permit the study of organisms in their natural habitat. Some of the typical tasks listed in the log books include pre-drilling inspection surveys, examination of outcrops, measurement of attitudes, collection of samples, and the study of coral barriers and atoll reefs. In a dramatic night dive, one of the NEKTONs severed cables entangling another submersible, DEEP QUEST, which was trapped in 400 feet of water. The NEKTON's also have been used in the recovery of a high performance speedboat and two acoustic beacons.

Another indication of the range of tasks which can be done using submersibles is contained in the promotional literature of Vickers Oceanics Limited, one of the largest submersible operators in the North Sea. The brochures advertise the following tasks for the Vickers series of PISCES submersibles:

1. underwater inspection
2. site route and survey
3. diver lockout
4. underwater working
    - impact wrench
    - drill
    - grinder/cutter
    - core/drill
    - chainsaw
    - guillotine
    - mud pump
    - Cox's gun
    - secateurs
    - handwheel operations
    - paint rig
    - wire brushing
    - explosive holecutting
    - underwater NDT
    - reciprocating saw
    - underwater burning
    - concrete chipper
    - underwater welding

In addition to their much publicized activities in the North Sea, submersibles have been used in many other locations throughout the world. The inventory in Appendix A identifies the areas in which the underwater vehicles were operating during 1975 and the major tasks or applications. This information is summarized in Table 4.1.

TABLE 4.1

INVENTORY OF UNDERWATER VEHICLES (1975)
(AREA OF OPERATION & APPLICATIONS)

AREA OF OPERATION APPLICATIONS	UNKNOWN	CONSTRUCTION OR DESIGN & DEVELOPMENT	NORTH SEA	GULF OF MEXICO	PACIFIC/ HAWAII	ATLANTIC	MEDITERRANEAN	OTHER	TOTALS
UNKNOWN	5	0	0	0	0	1	0	9	15
CONSTRUCTION, OR DESIGN & DEVELOPMENT	0	28	0	0	0	0	0	0	28
OFFSHORE OIL & GAS	0	0	12	0	0	0	1	1	14
MINING	0	0	0	0	0	0	0	0	0
RESEARCH	2	0	0	4	2	1	1	13	23
SURVEY/SAMPLING/ INSPECTION	7	0	0	0	1	1	0	2	11
RESCUE/SALVAGE	0	0	0	0	1	0	0	5	5
MILITARY	3	0	1	0	2	0	0	1	7
OTHER	15	0	0	0	1	1	1	3	21
TOTALS	32	28	13	4	7	4	3	34	125

Two categories were added for those vehicles under construction or in the design and development phase, and those vehicles for which the information on the area of operation or application is unknown.

The applications were grouped in the following categories:

1. offshore oil and gas (exploration and production)
2. mining
3. research
4. survey/sampling/inspection
5. rescue/salvage
6. military
7. other

The potential market for remote manipulator systems on underwater systems was analyzed for each of these applications (except 'other'). The requirements for fixed installations also were analyzed.

Offshore Oil and Gas

Present activities in the offshore oil and gas industry are concentrated in seven key areas: the Gulf of Mexico, the North Sea, the Persian Gulf, the Java Sea, Borneo, central West Africa, and the east coast of Spain. Promising areas in the early stages of exploration include the Beaufort Sea, the Labrador and west Greenland shelves, the continental slopes of the Gulf of Mexico and West Africa, and the Andaman Sea. Areas which show favourable geology but remain unexplored include the east coast of the United States, the Gulf of Alaska and the Bering Sea, the Gulf of Venezuela, the continental shelves of Argentina and Brazil, the west coast of central Norway, the Barents Sea, the Mediterranean, and the extensive shelf off the East China Sea.

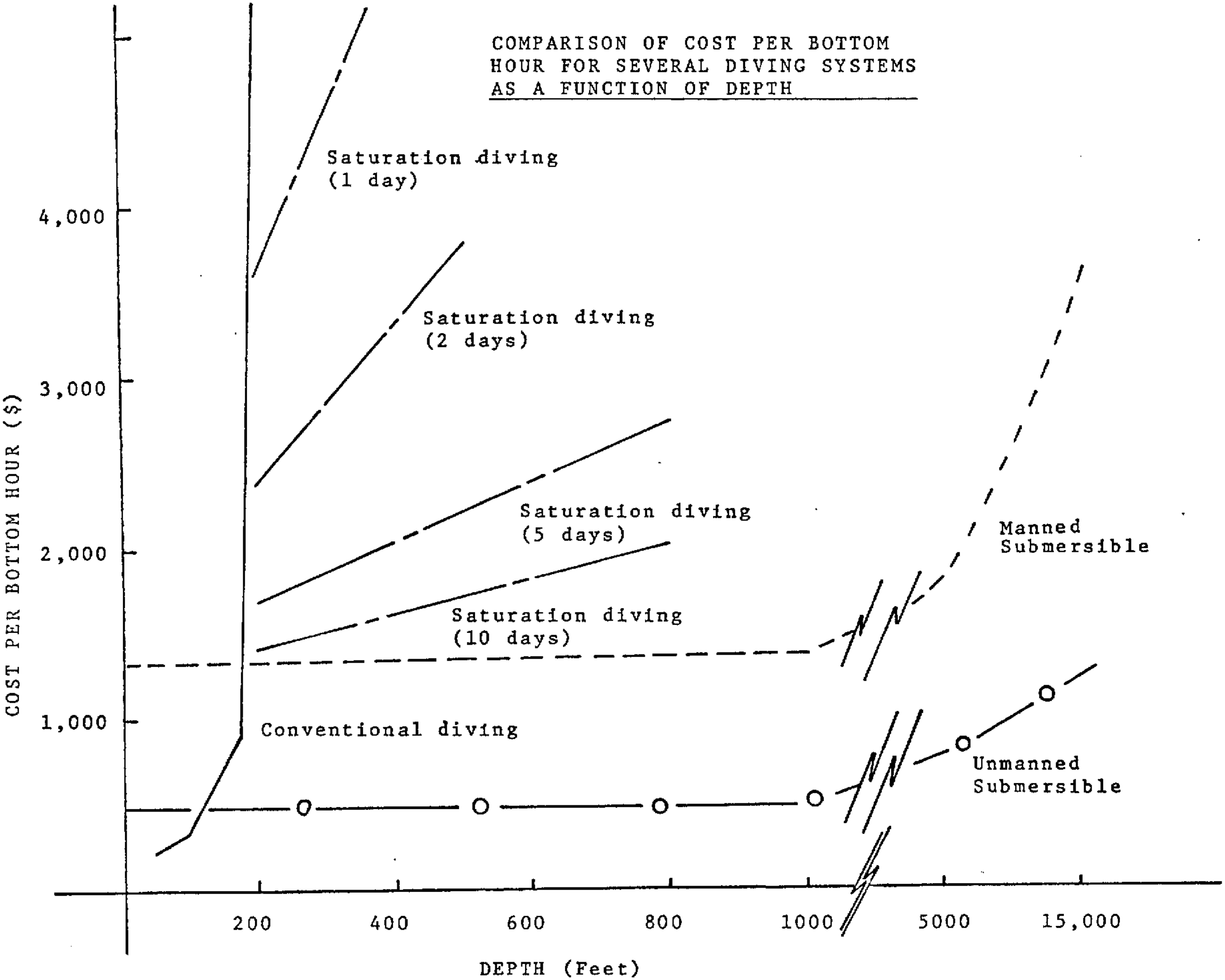
In the producing areas, the use of submersibles has been confined mainly to the North Sea (Table 4.1). Several reasons may be advanced to explain this.

Most of the producing wells are in relatively shallow water, 200 feet or less. At these depths, divers are less expensive and have shown more versatility. Comparative studies have shown that divers can complete tasks about four times faster, on average, than present rate-controlled manipulators. While manipulators can perform the actual task almost as fast as a diver, and usually more accurately, the time for alignment and travel is much greater.

Four factors will lead to increased use of submersibles - operations at greater depths, operations in colder waters, demonstrated experience with submersibles, and improved manipulator systems particularly in the areas of self-alignment, self-tool feed, torque limiting clutches, and force feedback.

Information presented at the M.I.T. collegium in February, 1976 can be used to estimate the depths at which submersibles become more economical than divers when assigned one task - in this example, welding. In Figure 4.3, data are plotted showing the approximate cost per bottom hour, as a function of depth, for conventional surface diving, saturation diving, manned submersible, and remotely operated work vehicles. The supporting data used in the derivation of these cost factors are presented in the "Notes to Accompany Figure 4.3".

These data show that to a depth of about 125 feet, conventional diving is the most economical. From 125 feet to almost 200 feet, the most economical system is a remotely controlled vehicle. However, the versatility of such vehicles in comparison to submersibles or conventional divers must be questioned. Below 200 feet, conventional diving becomes uneconomical because of the cost of helium oxide and the time lost in decompression. Saturation diving would be almost competitive with a manned submersible provided the dive lasted at least 10 days.



COMPARISON OF COST PER BOTTOM HOUR FOR SEVERAL DIVING SYSTEMS AS A FUNCTION OF DEPTH

FIGURE 4.3

1. for supporting data see Notes to Accompany Figure 4.3

NOTES TO ACCOMPANY FIGURE 4.3

Conventional Surface Divers

- based on a team of 4 welder/divers including contractor overhead where applicable.

- $500/day/diver

- includes depth bonus, diving and welding support equipment, decompression chamber (required below 50 feet), HeO2 breathing mixture (required below 200 feet).

Saturation Diving

- based on a team of 4 welder/divers including contractor overhead where applicable.

- one day decompression required for each 100 feet, regardless of job duration.

- $1200/day under pressure/diver

- $15,000/day for the saturation diving system, and for the welding and support equipment.

- $8,000/work day and $2,000/chamber day for mixed gases.

- 6 working hours/bottom day/diver.

Manned Submersible

- endurance of 12 hours
- $12,000/day surface support
- $80/hour for salary and consumables
- capital recovery of $0.03705/hour/foot.

Remotely Operated Work Vehicle

- operating endurance of several days
- $12,000/day surface support
- $35/hour for salary and consumables
- capital recovery of $0.03861/hour/foot

These data are presented to demonstrate relative, not definitive, costs. The analysis of offshore oil and gas activities is limited to those regions where activities are expected to extend to waters deeper than 500 feet (the area where submersibles become cost effective). Of all the producing offshore oil and gas zones, operations are extending to depths approaching 500 feet only in the North Sea.

When interviewed by Industrial Market Research Limited, of London, England, the major diving companies operating in the North Sea reported that diving technology was "sufficiently well developed to meet expected drilling programs in the North Sea. However, to eliminate the high risks of saturation diving, submersibles will become more important, particularly for pipeline laying, pipeline burial, pipeline servicing, and subsea well maintenance". The companies also expressed the belief that smaller, automated, unmanned submersibles equipped with television and radio recording instruments would be developed.

Six companies are competing for submersible work in the North Sea. The inventory in Appendix A (summarized in Table 4.2) lists 12 submersibles operating in the North Sea. Vickers Oceanics Limited (VOL) are reported to have a fleet of 12 submersibles operating in the area though current VOL literature lists only 10 of which at least one is under construction. The other five companies operating in the North Sea include P & O Subsea with five submersibles, Intersub with five submersibles, Comex with one, Skadoc with one, and Ocean Systems with one. This totals 22 submersibles operating in the North Sea. In actual fact, at least six of these are still under construction. Therefore there are probably between 12 and 16 submersibles operating, or on stand-by, in the North Sea (the midpoint of 14 submersibles is used in the following analysis).

Industrial Market Research Limited estimated that, in 1976, approximately 37 to 44 drilling rigs were operating in the North Sea (there were 36 in 1973). A report in Ocean Industry (May, 1974) quoted a projection of 100 drilling rigs in the North Sea by 1977/78 and 105 by 1981/82.

Vickers Oceanics Limited projects that their present fleet of 12 submersibles will increase to 18 submersibles by 1980 and 24 by 1985. Applying the same growth rates to the inventory of 14 submersibles competing for the charter business in the North Sea, yields a projected inventory of 21 submersibles by 1980 and 28 by 1986. This would imply a present ratio of approximately two drilling rigs per submersible and a projected ratio of about five by 1980 (there was no estimate of the number of drilling rigs expected beyond 1980).

As a first step in the analysis, the number of drilling rigs was assumed to be an approximate measure of the activity in the offshore oil and gas industry. A ratio of one submersible for every five drilling rigs was assumed for offshore oil and gas fields where the drilling depth exceeds or will exceed 500 feet. Cold regions where divers either cannot operate or are very inefficient because of the cold water were added. The result is an analysis based on the following regions: North Sea, Canada, Gulf of Mexico (additions only to present fields), West Coast U.S.A., East Coast U.S.A., Alaska, and Central and South America.

In 1975, two exploratory wells were drilled in the North Sea at a depth of 745 feet. The chief focus of exploration activity was in the 59°N to 62°N area where the depth exceeds 600 feet. There have been a number of discoveries of oil and gas fields in the Mackenzie Delta off northwestern Canada and several gas fields in the Arctic Islands. However, there has been only mediocre success along Canada's east coast and, to date, no commercially exploitable reserves have been found.

Exploratory drilling in the Gulf of Mexico has commenced in waters exceeding 600 feet in depth. One prospect, known as Cognac and leased by Shell, Amoco and others, has shown exciting promise and probably will contain the first deep wells in the Gulf (at 700 to 1,000 feet).

The opposition to exploration and drilling on the west coast of the U.S. has been overcome and the first sale of leases was held late in 1975. Preliminary seismic work has been carried out in several areas off the east coast of the U.S. The area looks very promising but production wells would be located in waters exceeding 1,000 feet.

Leases for the Gulf of Alaska are to be offered for sale sometime during 1976. There are several production wells operating off the coast of South America but to date drilling has not extended to the deeper waters.

The number of drilling rigs in each of the seven regions in 1973, and the number projected for 1977/78 and 1981/82, is displayed in Table 4.2.

By 1977-78 an additional 136 drilling rigs are expected in the seven regions and another 96 by 1981-82. Using the average of the 1977-78 and 1981-82 projections, and compensating for the fact that the base year is 1973 and not 1976 (note that the number of drilling rigs in the North Sea in 1976 was only slightly greater than the number in 1973), a requirement for an additional 175 drilling rigs by 1980 is estimated for the seven regions. Applying the factor of one submersible for every five drilling rigs, generates a demand for an additional 35 submersibles by 1980.

No estimates were found in the literature on the level of activity or expenditure projected by the offshore oil and gas industry beyond the year 1981-82. Vickers Oceanics Limited have estimated that their submersible fleet will increase from 1980 to 1985 by the same number which are expected to be added between 1976 and 1980 (i.e. a smaller percentage increase between 1980 and 1985 than between 1976 and 1980). Based on the same assumption for the total submersible fleet for offshore oil and gas activities, the inventory would increase from 1980 to 1985 by another 35 units.

Production drilling in deeper waters beyond the capabilities of divers is still at the planning stage. It is recognized that major advances in offshore drilling technology will be required. Also, many of the reserves are only estimated, not proven. For these reasons projections beyond 1985 are difficult. Therefore, as a minimum, a straight line projection is used to estimate number of submersibles to be built from 1985 to 1990 (35 submersibles). This should be a minimum since exploration and production in the offshore oil and gas industry is not expected to cease in 1985 and there will be a growing market for replacements as the total fleet grows.

In the analysis, it was assumed that each region was independent, that submersibles operating in one region would not be transferred to another. It could be argued that the services of submersibles would be chartered to the offshore oil and gas industry and therefore, when activity was declining in one field, the submersibles could be transferred to another. While this is a valid concern, it is assumed that the chartering of submersibles would be comparable to the chartering of the drilling rigs and therefore this would have been factored already into the projection of the number of drilling rigs.

On the other hand, the estimate may be considered low because no account has been made for other activities which will be associated

TABLE 4.2

PROJECTED NUMBER OF DRILLING RIGS IN 1977-78 and 1981-82

REGION	TOTAL DRILLING RIGS (actual & projected)		
	1973	1977-78	1981-82
North Sea	36	100	105
Canada	3	10	30
Gulf of Mexico	59	103	105
West Coast, U.S.A.	3	9	25
East Coast, U.S.A.	-	-	25
Alaska	-	-	20
Central and South America	27	30	50
TOTAL	128	264	360

Source: Ocean Industry, May 1974.

with the offshore oil and gas industry. Pipe laying and inspection are examples. Oil only began flowing in pipelines in the North Sea in 1975. The initial route of one of the first pipelines laid in the North Sea, the Ninian line, was rejected by Shell Oil because no access was apparent across Grut Wick, Shetland. Instead a line was started across Firths Voe. However, severe currents created many difficulties. Eventually BP found a route across Grut Wick after conducting a video survey by submersible.

While other pipelines are under construction, several severe technological problems will face the industry in deeper water. The area near 62^{O}N, for example, is punctuated with deep troughs and some companies are already reported to be considering other methods for transporting the oil. The first Brent oil field in the North Sea will have a spar floating storage unit with a capacity of 300,000 barrels. However, where pipelines are installed, submersibles can perform many tasks better than divers.

While pipelines will be constructed at many of the fields it is not an accepted fact that pipelines will become the primary mode of transportation from the deep water sites. For this analysis, it is assumed that tasks associated with pipeline laying and inspection will be done by the same submersible fleet estimated previously, with the possible addition of some unmanned submersible units.

Following the trend supported by the diving companies now operating in the North Sea, it appears that unmanned submersibles could take a part of the service market in the offshore oil and gas industry.

How large this market might be is difficult to estimate since no units are in operation at this time. Governments are now imposing strict regulations on the inspection and certification of structures in the North Sea. One Norwegian certifying authority, Det norske Veritas (DnV), estimates that by 1980, 650 people could be engaged in platform inspections and that, "for certain tasks, unmanned remotely controlled free swimming vehicles could be used. Non-destructive testing and cleaning equipment could be handled by manipulators or divers".[1]

As a conservative estimate, it was concluded for this analysis that five unmanned submersibles (equipped with some form of remote manipulator system) would be in use for the offshore oil and gas industry by 1980 and another 10 units would be added in each five year period from 1980 to 1990.

It was assumed that all of the submersibles in this market (manned and unmanned) would be equipped with a manipulator and that ten percent of the manned submersibles would be equipped with two. Therefore the potential market for new remote manipulator systems, generated by the activities in the offshore oil and gas industry, has been estimated at 44 units by 1980 and another 49 units in each five year period from 1980 to 1990.

There is no evidence at this time that sea bed vehicles or fixed installations equipped with remote manipulators will be required for the offshore oil and gas industry.

Mining

At recent conferences on the Law of the Sea, coastal states have expressed concern over the value and exploitation of resources within their jurisdiction. For example, it is estimated that more than 80 percent of the total resources of hydrocarbons under the sea bed lie within 200 nautical miles of the coastal states. All

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1. "Stringent Safety Rules Gives Boost to Underwater Technology", Offshore Engineer, October, 1975.

of the presently exploitable mineral resources, and most of those having potential economic value in the next several decades, also are located in this zone. In 1967, minerals recovered from the continental shelf were valued at approximately $680 million but this represents less than 1 percent of the world total mined in that year.

Much of the world's attention has been focussed on the occurrence and recovery of manganese nodules, particularly on the systems developed by Summa Corporation, a subsidiary of the Hughes Tool Company in the United States. However, with the realization that their goal was the recovery of a foreign submarine and not manganese nodules, interest in the subject appears to be diminishing. Also, surveys have demonstrated that the nodules are generally found in waters deeper than 6500 feet and at least 400 nautical miles from land.

Three major companies are reported to be involved in developing techniques for the offshore mining of manganese nodules: DeepSea Ventures, Kennecott Copper, and Ocean Resources. Rio Tinto-Zinc, a member of the Kennecott Copper consortium, has done an economic analysis which demonstrates that to be profitable an operation would have to harvest 3 million tonnes per year. A study by Metallgeselbschaft Preussag is more optimistic but still would require 10,000 tonnes per day (10 tonnes per minute, 24 hours a day).

The Japanese (part of Ocean Resources) have been working on a bucket system; Kennecott Copper have funded investigations of a drag dredge (determined to be economically impractical) and an airlift system. The airlift system has potential but an extensive engineering design and development program will be required. With the recovery rates required, it seems almost certain that submersibles will be impractical for production operations.

Other minerals which may be mined offshore can be divided into two major categories - heavy minerals such as diamonds, gold, and tin which are all high value commodities and other minerals such as sand and gravel, and calcium carbonate which are relatively abundant and inexpensive. The physical barrier of the sea gives rise to higher production costs than those encountered with land based minerals. This disadvantage has been overcome only for those minerals for which either production costs are small in comparison to market price (diamonds for example) or concentrations considerably exceed land deposits (tin is one example).

Even though projections indicate that vast mineral resources will be required before the end of this decade, reserves and resources from mining on land should be capable of meeting these projections. Minerals probably will be mined offshore only when it is economical or strategically important.

Based on this assessment, it appears most unlikely that underwater systems will be required for offshore mining in this century. Therefore we have assumed that the demand for remote manipulator systems to serve activities in offshore mining will be zero.

Research

In the inventory detailed in Appendix A, and summarized in Table 4.1, a total of 23 submersibles were identified as being involved in research activities. Of these, ten are operated by the USSR mainly in fisheries research, five by various groups in the U.S., five by France, two by Japan, and the last by the Department of the Environment in Canada.

The five underwater vehicles operated in the U.S. are engaged in a variety of activities. DEEP QUEST and DIAPHUS (or PC-8) are equipped with manipulators. NEMO and DEEPVIEW are built for observation only. It is not known whether PC-3X is equipped with a manipulator. The five submersibles operated by research organizations in France were all built prior to 1970 and include several of those built when the initial interest in underwater activities was near a peak - the ARCHIMEDE, the ARGYRONETTE and the S.P. 3000 are included in this category.

The future market for submersibles as vehicles from which to conduct research will depend, to a large extent, on the expenditures by governments for research and development on oceanographic projects. At this time, it does not appear that a market of any significant size will develop to serve this activity.

For this analysis, it is assumed that by 1980 only two more submersibles will be constructed for research purposes and equipped with remote manipulators. From 1980 to 1985, it is assumed that an additional three submersibles will be built, some to replace existing submersibles which will be scrapped or retired by that time. Other underwater vehicles probably will be built but they will be of lower cost, used for observation or photography, and not equipped with manipulators. From 1985 to 1990, it is assumed that an additional three submersibles will be built.

Search/Rescue/Salvage

Following the loss of the U.S.S. Thresher in 1963, the United States embarked on a vigorous program to develop a capability to effect a rescue at great depths. The result was the nuclear powered DSRV 1 (Deep Sea Rescue Vehicle) built by Lockheed. Since then Lockheed have built three more submersibles in the DSRV class. Other submersibles have been involved in some notable rescue and salvage operations - the salvage of the ALVIN by the ALUMINAUT and, more recently, the rescue of the PISCES III using CURV, an unmanned submersible.

Unmanned submersibles also have been used in salvage operations. CURV, a cable controlled underwater vehicle, was used to retrieve the H-bomb lost off the coast of Spain. In a less dramatic role, unmanned submersibles have been used for several years to recover payloads in armament ranges and to retrieve underwater monitoring packages and beacons.

The inventory in Appendix A lists six underwater vehicles assigned to rescue and salvage operations (excluding ordnance retrieval which is covered under the category "military"). Four of these vehicles are in the DSRV class; the other two are engaged in salvage operations and are used for cutting cables, clearing debris, and raising instrument packages.

With increased activities in the offshore oil and gas industry, almost certainly there will be a requirement for rescue capabilities for submersibles engaged in this area. This requirement for a search and rescue capability may be satisfied by submersibles built for other purposes. On the other hand, governments may require that, in future, a search and rescue capability be in force in a given offshore location where the activity level is significant. Because of the loss of divers in the North Sea, the United Kingdom has instituted stringent regulations affecting diver qualifications and operations. A private member's bill to legislate submersible safety was brought before the United States government. Although the bill was rejected, it demonstrates a growing concern for the safe operation of underwater systems.

Most of the underwater activities in which submersibles will be engaged will involve the offshore oil and gas industry. Other activities will be minor in comparison. Earlier in this section, it was argued that the major offshore oil and gas activity will be concentrated in seven areas:

1. North Sea
2. Canada
3. Gulf of Mexico
4. West Coast, U.S.A.
5. East Coast, U.S.A.
6. Alaska
7. Central and South America

Therefore, it is assumed that there will be a maximum of one submersible per region dedicated to search and rescue (such submersibles probably would be owned and operated by the respective coast guards). These search and rescue craft would be in addition to the four DSRV submersibles. The DSRV class has the capability for rescue at depths far in excess of those which will be required in the commercial sector. It is assumed that the DSRV class would be committed primarily to military activities but would be available to commercial interests in an emergency.

Safety measures rarely herald a major activity. They usually are introduced following a catastrophe or a long history of minor events. Therefore it is assumed that submersibles for each region dedicated to search and rescue will not be constructed before 1980 and probably would not be built until between 1980 and 1985. It is assumed that no additional submersibles for search and rescue will be required between 1985 and 1990.

Very few submersibles are dedicated to salvage or recovery operations, with the exception of those for the military and the offshore oil and gas industry. The analysis of salvage and recovery for these two activities is covered elsewhere in the report. Other than for these two activities, the requirements for salvage would appear to be small, possibly no more than one or two vehicles in each five year period. Therefore we have assumed one submersible for salvage and recovery operations in each five year period.

Survey/Sampling

The inventory identifies 11 underwater vehicles engaged in surveying and sampling; seven of these are unmanned. It is difficult to estimate the future level of activity for underwater surveying and sampling. While most of the activity would be related to the offshore oil and gas industry, there could be some initial surveying and sampling for offshore mining and perhaps mapping (soundings and charts). Submersibles may prove very useful for charting under ice.

It is assumed that because of the increased interest shown by coastal states in their offshore areas, the requirements for surveying and sampling will generate a requirement for three submersibles to be built by 1980, and then five in each five year period to 1990.

Military

The use of submersibles for ordnance recovery has already been noted. This has been the most significant use by the military. Future applications could include the installation and maintenance of unmanned sea-floor stations for underwater navigation and reconnaissance. With extended boundaries resulting from recent Law of the Sea conferences, underwater stations may develop as one system for maintaining surveillance of these vast areas.

There are at least seven submersibles being used by the military but no information is available on the nature of the activities. With an increase in the activities of the offshore oil and gas industry, the increased jurisdiction created by the extension of territorial waters to the 200 mile limit, and the potential increase in shipping activities in ice infested waters, it is anticipated that the use of submersibles, both manned and unmanned, by the military will increase.

With an extension to 200 miles, seven countries would have offshore areas greater than 1,000,000 square miles and 12 would have areas greater than 500,000 square miles. Assuming that 500,000 square miles of offshore area is one possible criterion for having an underwater surveillance and reconnaissance capability, and excluding the U.S.S.R., this leaves 11 countries as potential markets. Therefore it is assumed that a market for five submersibles will develop by 1980, and an additional ten in each five year period from 1980 to 1990, to serve military purposes.

Fixed Installations

To date, all the manipulators on underwater systems have been on submersibles, manned and unmanned, tethered and free. In addition to underwater vehicles, there is also a growing number of underwater habitats and fixed installations. These have been used mainly as underwater observation posts and to test man's ability to live for an extended period of time in "inner space".

Artists impressions have postulated an extension of these experiments to small underwater communities, equipped in some cases with manipulator systems. Since no permanent fixed underwater installations have been constructed, it is assumed that any application of remote manipulators to fixed underwater installations would not occur before 1985.[1] After 1985, it is assumed that there could be a market for 10 underwater installations by 1990.

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[1] General Electric has built one prototype system for the maintenance of an underwater wellhead completion system off Santa Barbara.

A summary of the market for underwater systems projected by Philip A. Lapp Limited to the year 1990 is presented in Table 4.3, by major area of application.

The projection of 51 additional underwater systems by 1980, and another 71 by 1985, represents the number of submersibles, or underwater vehicles, not the number of remote manipulator systems. In the analysis of the offshore oil and gas industry, it was assumed that all manned submersibles would carry at least one manipulator, that ten percent would carry two manipulators and that all unmanned submersibles would be equipped with one. Some of the submersibles in the research category are used mainly for observations and photography. Therefore it is assumed that every third submersible in this category would be equipped with a remote manipulator. For the submersibles in the search/rescue/salvage category, it is assumed that each would be equipped with two manipulators.

It is assumed that every second submersible in the surveying/sampling and military categories would have one manipulator. For the category "other" (or fixed installations) a factor of one was used. Based on these factors of the number of manipulators per submersible, the total projected market for remote manipulator systems for underwater applications would be 50 by 1980, an additional 74 from 1981 to 1985, and another 60 from 1986 to 1990. (Table 4.4).

The inventory in Appendix A identifies 73 submersibles and sea-bed vehicles equipped with remote manipulator systems. It is generally accepted that these present manipulators have limited capabilities. Therefore it is reasonable to postulate that as improved manipulators are developed a market will grow for the retrofit of improved manipulators to existing submersibles.

TABLE 4.3

PROJECTED MARKET FOR ADDITIONAL UNDERWATER SYSTEMS[1] TO 1990

AREA OF APPLICATION	TO 1980	1981 - 1985	1986 - 1990
Offshore Oil & Gas			
- manned	35	35	35
- unmanned	5	10	10
Mining	0	0	0
Research	2	3	3
Search/Rescue	0	7	0
Salvage	1	1	1
Surveying/Sampling	3	5	5
Military	5	10	10
Other (primarily fixed installations)	0	0	10
TOTAL	51	71	74

1. underwater vehicles, fixed installations, and habitations.

TABLE 4.4

PROJECTED MARKET TO 1990 FOR REMOTE MANIPULATOR SYSTEMS FOR UNDERWATER APPLICATIONS

AREA OF APPLICATION	FACTOR-NO. OF MANIPULATORS PER SUBMERSIBLE	To 1980	1981 - 1985	1986 - 1990
Offshore Oil & Gas				
- manned	1.1	39	39	39
- unmanned	1.0	5	10	10
Mining	N/A	-	-	-
Research	0.3	1	1	1
Search/Rescue	2.0	0	14	0
Salvage	2.0	0	2	2
Survey/Sampling	0.5	2	3	3
Military	0.5	3	5	5
Other (primarily fixed installations)	1.0	0	0	10
Retrofit to existing submersibles	-	15	22	0
TOTAL		65	96	70

N/A - not applicable

For this analysis, it is assumed that by 1980 retrofits will be made to at least 20 percent of existing underwater vehicles known to have remote manipulators (73) and to an additional 30 percent from 1980 to 1985 (also assuming an average of one retrofit manipulator per submersible). This retrofit market has been added to the market forecast presented in Table 4.4. The result is a market projection of 65 manipulators by 1980, another 96 by 1985, and 70 more by 1990.

It is widely accepted that the remote manipulator systems currently used for submersibles are very elementary. As the application of submersibles to underwater tasks increases, more advanced remote manipulators will be required. Improvements such as force-feedback, interchangeable tools, more versatile end effectors, and new lighting systems will make submersibles more effective. To reflect this evolution, three unit prices were introduced to estimate the potential market - $100,000, $250,000, and $500,000.

The $100,000 model would be compatible with the remote manipulators available to-day. Applying the technology from the Shuttle RMS program could result in an advanced model at a price of approximately $250,000. The $500,000 model would be the result of several years development and operating experience and would be an extremely versatile and powerful device.

No submersible will be equipped with a $500,000 manipulator for some time. This would be incompatible with the present costs of the vehicle itself. Therefore it is assumed that until 1980 the majority of manipulator systems would be priced in the $100,000 range. By the late 1970's, models priced in the $250,000 range should begin to appear on the market and by the 1980's the more sophisticated $500,000 models. It is assumed that the market share for the $250,000 model will grow by 10 percent every five years to a maximum of 40 percent and the market share for the $500,000 model by 5 percent every five years to a maximum of 20 percent.

These estimates of market share are summarized in Table 4.5.

TABLE 4.5

PROJECTED MARKET SHARE TO 1990 FOR THREE MODELS OF REMOTE MANIPULATOR SYSTEMS FOR UNDERWATER APPLICATIONS

MODEL	PROJECTED MARKET SHARE (%)		
	TO 1980	1980 - 1985	1985 - 1990
$100,000	90	75	60
$250,000	10	20	30
$500,000	0	5	10
TOTAL	100	100	100

4.2 Marketing Considerations

The underwater market is a relatively new market both in the use of submersibles as work platforms and the utilization of remote manipulators. Manufacturers build submersibles to meet a customer's specific requirements. When a remote manipulator system is required, the submersible manufacturer designs and builds the hardware for the specific task.

An operator in the oil and gas market would rarely buy a submersible to meet the requirements of his own activities, almost all would be leased. Oil companies drilling in the North Sea, for example, would not purchase submersibles, just as they do not purchase other major items of capital equipment such as drilling rigs or pipe laying barges; the services are leased from other companies. Vickers Oceanics Limited (VOL) is one example of a leasing company. VOL buys submersibles from manufacturers, such as Perry or International Hydrodynamics, and leases the services to other companies, such as the oil companies operating in the North Sea.

Therefore the underwater market has three separate identities: the submersible manufacturer, the leasing company, and the customer for the leasing services. The customer for the leasing services is not interested in the specifications of the submersible, or the equipment on-board; he is interested only in the services which can be performed and the cost. The submersible manufacturer is interested primarily in the craft itself. Any equipment, such as a remote manipulator, is secondary to his main line of business. Therefore the important customer is the middle link, the leasing company.

If manipulator systems were available which could be fitted to the existing submersibles of the leasing company and which would improve or expand the services offered, then the leasing company would be the most receptive link in the chain. Once new manipulator systems are installed and operated on existing submersibles, the leasing company would begin to direct the submersible manufacturer to fit the systems to any new submersibles ordered. After that step, the submersible manufacturers may develop as a second market for underwater applications.

Until recently, the competition for remote manipulator systems for underwater applications was represented by the submersible manufacturer. Now, other companies are becoming involved in the design and development. General Electric, for example, are working with Oceaneering International in Houston to develop a "force feedback" underwater manipulator system. The first installation will be on a diving bell. It is expected that the vehicle, with the manipulator system, will be used in exploratory drilling work in the offshore oil fields.

There are presently three manufacturers of remote manipulators in Canada, International Hydrodynamics and McElhanney Off-Shore Surveying Engineering Limited on the West Coast, and Deep Diving Systems Ltd. in Thunder Bay, Ontario. All three are principally submersible manufacturers. Though the market is very new, the competition in Canada is becoming very strong!

4.3 Potential Market Penetration

While the projected market is small in comparison with the other markets analyzed in this report, it does represent the market for a product whose systems and technologies closely parallel those of the Shuttle RMS. Furthermore Canadian industry would be dealing, at least in the first years, mainly with companies which are familiar with the purchase of large systems and with the application of advanced technology. Vickers and P & O Subsea are examples of companies with these characteristics.

Canadian industry should be in a excellent position to capture a share of this market. The required systems, particularly for the more advanced models could be very similar to the remote manipulator systems developed for the Shuttle RMS. Therefore, for the $500,000 model, it is assumed that Canadian industry could capture 75 percent of the market and maintain this dominance through to the end of the 1980's due to the developments in skills and technologies gained on the Shuttle RMS program.

For the $250,000 model an initial penetration factor of 50 percent was assumed. This is projected to decline by increments of 5 percent. A decline in market penetration is expected because the market is new and the potential competition is presently limited. As the market develops, other companies can be expected to enter forcing the market share to decline.

The $100,000 model is assumed to represent the remote manipulators availble to-day. Developments from the Shuttle RMS program are not expected to affect this model significantly. Therefore, because this analysis is directed to an estimate of the potential market for developments from the Shuttle RMS market, a market penetration factor of zero is applied to the $100,000 model. Note that this does not imply that Canadian industry will not sell remote manipulators at this price level, but rather that they will be able to do so without relying on systems or technologies from the Shuttle RMS.

All of these estimates of market penetration are summarized in Table 4.6.

TABLE 4.6

ESTIMATED PENETRATION OF THE UNDERWATER MARKET FOR REMOTE MANIPULATOR SYSTEMS

MARKET APPLICATION	ESTIMATED MARKET PENETRATION (%) 1976 - 1980	 1981 - 1985	 1986 - 1990
UNDERWATER			
- $100,000 MODEL	0	0	0
- $250,000 MODEL	50	45	40
- $500,000 MODEL	0	75	75

4.4 The Potential Market (Underwater) and a Comparison with the Previous (1974) Trend Analysis

Applying the market penetration factors from Table 4.6, and the market share factors from Table 4.5, to the projected number of manipulators in Table 4.4, generates an estimated market of $9.3 million to the end of the 1980's (summation of the sub-totals in Table 4.7).

Because of the projected price of the remote manipulator systems and the extreme environmental conditions under which they will operate, a substantial market should develop for spares, and repair and overhaul capabilities. Canadian industry has experience in both these areas in the aircraft industry. For this reason, we have assumed that Canadian industry could obtain a significant portion of the spares, and repair and overhaul business in the underwater market. An estimate of the potential market was developed by assuming that the market for spares and repair and overhaul would be 50 percent of the total sales of remote manipulator systems in the previous quinquennial. It also was assumed that Canadian industry could capture 50 percent of this business. The value of this segment of the market is shown in Table 4.7.

Including spares, and repair and overhaul, the total market is projected to increase from an average of $160,000 per year by 1980 to $1,600,000 per year by the end of the 1980's - a total market of $14.8 million.

This market projection for remote manipulator systems for the underwater market is considerably less than a previous estimate made in 1974. The most significant reason for this dramatic reduction is that the previous analysis simply assumed that the necessity to exploit offshore resources, notably oil and gas, and the potential

TABLE 4.7

PROJECTED SALES OF REMOTE MANIPULATOR SYSTEMS TO THE UNDERWATER MARKET[1]

MARKET APPLICATION	PROJECTED SALES ($ millions)		
	1976-1980	1981-1985	1986-1990
UNDERWATER			
- $100,000 MODEL	$ 0.0	$ 0.0	$ 0.0
- $250,000 MODEL	0.8	2.1	2.0
- $500,000 MODEL	0.0	1.8	2.6
SUB-TOTAL	$ 0.8	$ 3.9	$ 4.6
SPARES & REPAIR & OVERHAUL [2]	$ 0.0	$ 1.9	$ 3.6
TOTAL	$ 0.8	$ 5.8	$ 8.2

1. derived by applying the unit prices, the market penetration factors in Table 4.6, and the model market share factors in Table 4.5 to the projected total number of manipulators in Table 4.4.

2. assumed equal to 25% of the total market (that is, excluding the application of market penetration) in the previous quinquennial (50 percent of the total market times 50% penetration).

Other countries, notably France, Italy, and Spain, have made large commitments to nuclear power in response to the oil crisis and many of the emerging third world countries are embarking on new nuclear programs. The first nuclear power plants are expected in Africa by 1981; by that time there could be more than 8 GWe installed in Asian countries, excluding Japan.

5.1 Market Analysis

In the U.S., the capital cost of a nuclear power plant, exclusive of initial fuel load, has reached $870/kWe. Capital costs for French and German reactors are slightly less. At $870/kWe, the recent IAEA projections represent business opportunities of $100 billion by 1980, another $290 billion by 1985, $410 billion by 1990, and $1,300 billion between 1990 and the end of the century. Approximately 43 percent covers direct costs. The other 57 percent is for indirect costs, interest on money used during construction, and escalation.

Of the 43 percent in direct costs, about 13 percent is for the components of the nuclear "island" and 20 percent of that amount for fuel handling systems. These ratios convert to a factor of $10.00/kWe out of a total capital cost of $870/kWe. Therefore, based on the IAEA projections, the total market for fuel handling systems could exceed $1.1 billion by 1980, another $3.4 billion between 1980 and 1985, $4.8 billion between 1985 and 1990, and another $15 billion to the end of the century. Almost all of this market would be represented by limited sequence manipulators.

The IAEA forecasts of installed nuclear capacity are given year by year to 1992, and for the year 2000, by country. These forecasts were grouped by region and the cost factor of $10/kWe applied to yield an approximate market forecast, by region, for fuel handling systems (Table 5.1).

The loading and unloading of fuel in a nuclear reactor takes place in the presence of high radiation levels. Fuelling of the CANDU series of nuclear reactors which use natural uranium and a heavy water moderator takes place daily. The fuel bundles are changed

TABLE 5.1

MARKET FORECAST FOR FUEL HANDLING SYSTEMS IN NUCLEAR POWER PLANTS (1976-1990)

($ Millions)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
EUROPE	132	92	90	143	179	211	208	200	408	295	268	330	333	360	375
CANADA	8	7	8	13	11	11	12	30	22	35	32	40	40	60	50
U.S.	74	71	72	64	140	198	240	260	270	260	290	320	350	400	440
OTHER AMERICA	-	6	-	9	8	8	26	16	36	22	36	40	40	50	60
NEW ZEALAND & AUSTRALIA	-	-	-	-	-	-	-	-	-	-	-	-	17	-	5
JAPAN	16	20	20	20	20	70	60	60	50	60	70	60	70	60	110
OTHER ASIA	2	14	6	6	10	33	38	37	59	65	68	90	70	100	110
AFRICA	-	-	-	-	-	-	9	-	9	8	8	-	15	-	15
TOTAL	182	210	196	260	368	531	593	603	854	745	772	880	935	1030	1165

during on power conditions and therefore in a highly radioactive environment. In the CANDU reacotr, the fuelling procedure is handled by two identical fuelling machines connected to each end of the fuel channel. One machine introduces the new fuel; the other accepts the spent fuel. The spent fuel is stored on the site, under water, and later transferred either to a reprocessing plant to extract the plutonium, or to a permanent storage facility.

In the U.S. systems, both the new and spent fuel in a reactor are radioactive and must be handled with care. Reactors using enriched uranium usually are fuelled once a year and the reactor is shut down until the complete core is changed. Therefore the fuelling systems are not as complex as those in the CANDU system of reactors. However there is a requirement for suitable equipment to handle the fuel assemblies from their entrance to the reactor facility, during insertion in the reactor core and finally removal to a cooling pond. The spent fuel assemblies are left in the cooling ponds to allow fission product decay heat to reduce to an acceptable level before transport.

Radioactive wastes are generated in almost all phases of the nuclear fuel cycle and accumulate as either solids, liquids, or gases at varying radiation levels. These phases include fuel enrichment, waste disposal, fuel reprocessing, and surveillance and maintenance. Since the handling of radioactive material is required in all these operations, some form of remote manipulator system or other protective measure is required. The IAEA estimates the capital investment required in each of these phases to be;

FACILITY	CAPITAL COST FACTOR*
1. conversion to uranium hexaflouride	$15/kgU/yr
2. enrichment	$300/kgU/yr
3. fuel fabrication	$100/SWU/yr
4. reprocessing	$380/kgU/yr

Applying these capital cost factors to the world fuel cycle requirements, and taking into consideration the capacities already installed in 1975, the IAEA projects that the additional capital requirements for each five year period from 1976 to 1995, will rise from $15 billion to approximately $25 billion. The estimates for each type of facility and each five year period are presented in Table 5.2. These costs include interest during construction.

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* kgU/yr - kilograms of uranium per year.
SWU/yr - separative work units of uranium per year.

TABLE 5.2

ESTIMATED CAPITAL COSTS FOR WORLD FUEL CYCLE REQUIREMENTS 1/

FACILITY	PROJECTED MARKET ($ Millions) 1976 - 1980	1981 - 1985	1986 - 1990
1. CONVERSION TO URANIUM HEXAFLUORIDE	$ 300 - $ 500	$ 600 - $ 800	$ 700 - $1,000
2. ENRICHMENT	9,000 - 13,000	12,000 - 17,000	16,000 - 22,000
3. FUEL FABRICATION	300 - 400	800 - 1,000	1,000 - 1,400
4. REPROCESSING	3,200 - 3,600	3,800 - 4,800	5,200 - 6,200
TOTAL	$12,800 - 17,500	$17,200 - 23,600	$22,900 - 30,600

1/ developed by the International Atomic Energy Agency; both high and low estimates presented.

No estimates were discovered in the literature on the cost of handling equipment at these facilities. The cost of fuel handling systems in a nuclear power plant represents approximately one percent of the total capital costs. Since uranium hexafouride, the output from the conversion facility and the feedstock for the enrichment process, is not radioactive, it is assumed that remote manipulator systems will not be required in conversion plants.

If it is assumed that one percent of the capital cost for the three types of facilities (enrichment, fuel fabrication, and reprocessing) would be allocated to remote manipulator systems, the market could expand from an average of almost $30 million per year during the next five years to an average of over $50 million per year during the last five years of the planning period (Table 5.3). Remote manipulator systems in these facilities would be more compatible with the systems developed for the space Shuttle RMS than the limited sequence manipulators used for fuel handling in the nuclear reactor.

A dramatic example of the potential danger at facilities handling radioactive material is illustrated by the reports of an accident in August, 1976 at the Atlantic Richfield Hanford reprocessing plant. A chemical reaction in a "glovebox", a sealed area through which workers operate using rubber gloves, led to an explosion which sent radioactive material out into the room and contaminated 10 workers. It is possible that the contamination could have been avoided if remote manipulators had been used. The manipulators would have permitted better insulation between the operator and the accident and, at least, a safer operating distance.

Other potential applications of remote manipulator systems in radioactive environments include inspection and maintenance tasks. In the inspection mode, remote manipulators could be used to locate leaks or detect broken fuel bundles in the reactor. Spar has built one

TABLE 5.3

PROJECTED MARKET FOR REMOTE MANIPULATOR SYSTEMS IN NUCLEAR FUEL CYCLE FACILITIES [1/]

FACILITY	PROJECTED MARKET ($ Millions) 1976 - 1980	1981 - 1985	1986 - 1990
CONVERSION TO URANIUM HEXAFLUORIDE	$ 0.0	$ 0.0	$ 0.0
ENRICHMENT	110.0	145.0	190.0
FUEL FABRICATION	3.5	9.0	12.0
REPROCESSING	34.0	43.0	58.0
TOTAL	$147.5	$197.0	$260.0

1/ factor of one percent applied to the average of the high and low estimates in Table 5.2.

breadboard unit for AECL and Ontario Hydro to test at the Pickering Nuclear Generating Station. If the design is successful, similar systems could be installed on other CANDU reactors. Princton University has expressed interest in a similar system for their experimental work on fusion reactors.

There has been at least one incident recorded at the Pickering Nuclear Generating Station when the fuelling machine would not unlock from the fuel bundle. This created a serious problem because of the high radiation levels involved. It was impossible to approach the fuelling machine. Eventually repairs were made but the task would have been simpler with a remote manipulator system designed for repair operations. Such a system could find application in all types of reactor systems.

For this study, it was estimated that the market for remote manipulator systems designed to do inspection and maintenance tasks in a radioactive environment will be equivalent to one unit at a cost of $250,000 per unit for every GW(e) of installed nuclear capacity. These factors translate to a potential market which is roughly equivalent to two and one-half percent of the market for fuel handling systems in nuclear generating plants and fuel cycle facilities. The results of applying this rate of 2 1/2 percent to the estimated capital costs for fuel handling systems in nuclear generating plants, and enrichment, fuel fabrication, and reprocessing facilities are presented in Table 5.4. This market can be expected to grow from $34 million in the 1976-1980 period to $191 million by the 1986-1990 period.

TABLE 5.4

PROJECTED MARKET FOR REMOTE MANIPULATOR SYSTEMS IN RADIOACTIVE ENVIRONMENTS AND FOR INSPECTION AND MAINTENANCE SERVICES

	MARKET ($ Millions)		
Market Application	1976 - 1980	1981 - 1985	1986 - 1990
Nuclear Power Plants (Table 5.1)	$1,216	$3,326	$4,782
Fuel Cycle Facilities (Table 5.3)	147	197	260
Sub-Total	$1,363	$3,523	$5,042
Inspection & Maintenance (2 1/2% of sub-total)	$ 34	$ 88	$ 126
TOTAL	$1,397	$3,611	$5,168

5.2 Marketing Considerations

The nuclear market is heavily supported in many countries by government, or quasi-government, agencies. The U.S. market is an exception. Several of the large utilities are either private or public companies and not subject to government regulation or pressure concerning domestic content. Canadian utilities, on the other hand, always attempt to maintain as high a degree of domestic content in the construction as is economically and feasibly possible. Utilities in other industrialized nations, such as the United Kingdom, Japan, Germany, and France follow similar practices. Because many of the sales in industrialized countries are for reactor systems designed by U.S. companies, as much of the generating station as possible, outside of the "nuclear island", is built by local industry under licence.

The emerging nations on the other hand have very little local industry capable of fabricating the components of a nuclear generating station. In these countries, the potential market for imported systems should be much higher.

Therefore, sales in the nuclear market would depend on the jurisdiction where the sale is made. For example, in Ontario, nuclear generating stations are commissioned by Ontario Hydro which acts as prime contractor for the major systems in the station. The major systems suppliers, in turn, are responsible for the sub-systems and associated subcontracts. In some cases, Ontario Hydro administers many of the small contracts for parts and services which are not included in one of the major systems.

Canadian General Electric supplied the fuel handling machines for the Pickering and Bruce Generating Stations. CGE was part of the system design team and was responsible for contracting out those components not manufactured by the company itself. Any changes to the present fuel handling system, or the introduction of a new system, must be approved by the Atomic Energy Commission Limited (AECL) and a model must be built for testing.

In the United States, the utility contracts for a nuclear generating station from a supplier who is responsible for the complete station. Westinghouse, for example, markets one reactor system. If a utility buys a Westinghouse system, then Westinghouse assumes the complete responsibility for the construction of the facility, turning it over to the utility when it is complete. Therefore, the supplier of the nuclear station, in this example Westinghouse, would be the customer for any remote manipulator system.

The market structure for nuclear generating stations in other countries is similar to the United States, with one notable change. The prime contracting role may be handled by a consulting engineering company which would assist the utility in selecting the supplier of the nuclear steam supply system - the nuclear component of the generating station. In this case the customer for a remote manipulator system would be the engineering consulting company. (Gibbs and Hill in New York is one example of an engineering consulting company who have performed the role of prime contractor on many nuclear power plants outside the United States).

The competition in the nuclear market is very strong. In the Canadian market, Canadian General Electric supplied fuelling machines for the Pickering Generating Station and will supply the same equipment for the Bruce Generating Station. For the Douglas Point Station which preceded Pickering, Ontario Hydro acted as the prime contractor on the fuelling machines; the largest sub-system supplier for that contract was Standard Modern. With the transfer of the prime contracting role to Canadian General Electric, Ontario Hydro virtually sealed off the market to competition in this area. Until the system requires a major design effort, it appears unlikely that another company could mount a serious threat to Canadian General Electric's position in the Canadian nuclear power plant market.

There are two major suppliers of nuclear generating stations in the United States: General Electric and Westinghouse. In both companies, the major systems work is done in-house. Only minor sub-systems and components are purchased outside. Therefore, there would appear to be little opportunity in the U.S. market for a supplier of fuel handling equipment for nuclear generating stations (particularly when General Electric are also major suppliers of remote manipulator systems in other markets).

The most promising area for a new entrant to supply remote handling systems to the nuclear market would seem to be in specialized equipment for inspection and maintenance, waste disposal, and facilities in the fuel cycle, particularly enrichment and reprocessing. Further, this market is more directly related to the systems being developed for the space Shuttle.

5.3 Potential Market Penetration

The nuclear market was analyzed in two segments: the requirement for fuel handling in the nuclear power plant (by far the largest market), and the requirements for facilities in the fuel production chain and for inspection and maintenance. Analysis of the first segment of the market, the nuclear power plants, indicates that the competition is firmly established in the market and the cost of establishing a competitive position would be very high.

For this study, it was assumed that Canadian General Electric will continue to supply fuel handling machines for the CANDU series of nuclear reactors in Canada. Because of the market structure, it seems unlikely a Canadian company will be penetrating world markets for fuel handling systems in nuclear power plants. Therefore, for this study a market penetration factor of zero was assumed for this segment of the market.

The growth in the construction of new facilities for the fuel cycle business probably will lag slightly behind the growth of new reactors. With the apparent easing of restrictions in the United States on the construction of new reactors, the facilities for fuel production (enrichment, fuel fabrication, and reprocessing) should be required by the early 1980's. While there should be a small market developing during the latter part of this decade, it was assumed that the facilities would rely on present technology. Therefore, a penetration factor of zero was assumed for the fuel cycle facilities market before 1980. An initial market penetration factor of one percent is assumed for the 1980-1985 period rising to 5 percent by the next five year period, 1986-1990.

AECL already is involved in the development of an inspection and maintenance unit. Because of this initial effort, a market penetration factor of one percent was assumed for the first five year period, 1976-1980. This is projected to increase to 5 percent by the next planning period and to 10 percent by 1986-1990.

These estimated market penetration factors are summarized in Table 5.5.

TABLE 5.5

ESTIMATED PENETRATION OF THE NUCLEAR MARKET FOR REMOTE MANIPULATOR SYSTEMS

MARKET APPLICATION	ESTIMATED MARKET PENETRATION (%)		
	1976-1980	1981-1985	1986-1990
NUCLEAR			
Nuclear Power Plants[1]	0	0	0
Fuel Cycle Facilities	0	1	5
Inspection and Maintenance	1	5	10

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[1] Fuel handling.

5.4 The Potential Market (Nuclear) and a Comparison with the Previous (1974) Trend Analysis

The penetration factors in Table 5.5 were applied to the market projections in Table 5.4 to derive an estimate of the potential sales of remote manipulator systems by Canadian industry. The results are presented in Table 5.6. The data in this table show a total potential market of $32.3 million to the end of the 1980's. The total projected market in the 1974 analysis was approximately the same. However, in the 1974 analysis, it was assumed that Canadian industry would concentrate on the market for fuel handling in nuclear power plants. Now, investigations for the present study reveal that, for several reasons, this segment of the market would be very difficult to enter.

However, the supporting markets such as the facilities in the fuel cycle, appear to show good sales potential. These markets were discussed in the 1974 analysis but not estimated.

Therefore, while the two market projections are similar they are in fact for different market segments. For this reason, a graphical comparison of the projected sales trends from the two studies would have no meaning and is not presented.

TABLE 5.6

PROJECTED SALES BY CANADIAN INDUSTRY OF REMOTE MANIPULATOR SYSTEMS TO THE NUCLEAR MARKET[1]

MARKET APPLICATION	PROJECTED SALES ($ millions)		
	1976-1980	1981-1985	1986-1990
NUCLEAR			
Fuel Cycle Facilities	$ 0.0	$ 2.0	$ 13.0
Inspection & Maintenance	0.3	4.4	12.6
TOTALS	$ 0.3	$ 6.4	$ 25.6

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1. derived from applying the market penetration factors in Table 5.5 to the projections of total market in Table 5.4.

6.0 THE INDUSTRIAL MARKET

6.1 Market Analysis

To many people the word "robot" is synonymous with science fiction. The mention of robots creates images of automatons ambling along with blinking lights, rolling across planetary landscapes, or sweeping floors and dusting. Even people with a more realistic view associate robots with sophisticated electronics and mechanics, and high cost.

Manufacturers of industrial robots cite these false impressions as the principle reasons holding back the bright future once predicted for this market. Although industrial robots have proven to be both technically and economically feasible in a number of applications, the total number in operation remains relatively small in comparison to the number of potential applications. By 1970, the largest U.S. manufacturer of industrial robots (over 80 percent of the dollar volume) had sold less than 200 units in the United States.

In a confidential multi-client study conducted in 1972, the Stanford Research Institute, perhaps reflecting the pessimistic attitude of the industry, estimated that by the end of 1975 there would be 2,800 industrial robots (including limited sequence manipulators) in the United States, and 2,200 in Western Europe and Japan. The Robot Institute of America reported the actual world population at just over 6,000 by the end of 1975 with 2,500 in the United States. Another estimate places the total population at 3,500. While sales have increased over the past five years, the manufacturers believe that a considerable marketing effort is still required to demonstrate the advantages of industrial robots.

The manufacturers emphasize four reasons for considering the use of manipulators or robots, in industrial applications:

1. the growing demand from people in industry to be relieved of dull, repetitive routine.
2. to increase productivity at a rate faster than the rising costs of material and labour (the economic advantage).
3. the use of skilled labour in unskilled occupations (underutilization of manpower).
4. new and more stringent job safety standards.

Manufacturers point to the variety of jobs now being done by robots including loading and unloading operations, spray painting, welding, and assembly. In their 1972 study, the Stanford Research Institute conducted a survey of the use of robots in the United States, Western Europe, and Japan. The differences in application by geographic area are demonstrated in Table 6.1.

These differences reflect the initial requirements for industrial robots in each area. In Europe, the Trallfa robot was introduced for paint spraying; in the United States the requirement was for spot welding and die casting operations (loading and unloading), and in Japan injection molding, forging, and press feed were the initial tasks where robots were introduced.

Before the markets for industrial robots grow to the levels expected, manufacturers realize that extensive marketing efforts will be required to educate industry. Business Week recently reported that Unimation, one of the world's largest manufacturers of industrial robots, was sponsoring seminars to inform the business community about the various applications of industrial robots. While sales do not usually result directly from the seminars, several people later returned to Unimation to purchase industrial robots for applications they had assessed on

TABLE 6.1

PERCENT OF INDUSTRIAL ROBOT APPLICATIONS BY GEOGRAPHIC AREA (1971)[1]

	UNITED STATES	WESTERN EUROPE	JAPAN
LOADING/UNLOADING	52%	51%	68%
PAINT & FRIT SPRAYING	4	26	2
WELDING	14	15	7
ASSEMBLY	1	-	1
OTHER	29	8	11
TOTAL	100%	100%	89%[2]

1. data from "Industrial Robots: An Opportunity". Stanford Research Institute, Menlo Park, California, 1972.

2. percents do not sum to 100 in original report.

returning to their plants. One of the principal aims of the seminar series has been to demonstrate that industrial robots are flexible. They can be programmed to do a wide range of jobs and are not limited to one application.

Following are a few vignettes illustrating specific applications of industrial robots:

> "At Mitsubishi Motors, one of the most unpleasant tasks was the dipping of front wheel suspension metal bushes. The solution emitted unpleasant odours and burns often resulted from the termperature treated bushes or the hot solution. Because of the safety aspects of the job and because labour is difficult to recruit as the company expands, Mitsubishi installed a robot at the heat treatment position. It was very successful and Mitsubishi now plan to install 10 to 20 robots in the body assembly section alone".
>
> "At Honda Motor Company a robot envelops the bodies of Honda's Civic and Accord models one by one and welds them at 130 points in 45 seconds. The process used to take 32 minutes and 30 seconds using a team of 30 workers. Since the introduction of the robot, productivity has increased by 10 percent".
>
> "At the Ford Motor Company Dearborn Frame Plant the presses once required four man crews. With the assistance of industrial robots, the labour input has been reduced to two man crews".
>
> "At the Evinrude Motors Division of Outboard Marine Corporation, robots pick up 2 1/2 lb. crankshafts individually from the end of a storage-bin chute and move them to a walking-beam system for movement through a grinding and gaging station. Then each one is gripped by another robot and deposited in a preset pattern on a pallet. The operation runs three shifts per day".

The American Machinist, in a special report published in 1975, defined eight degrees of mechanization varying from the use of a non-powered tool to do manual tasks (level one) to "powered mechanisms controlled by one of several methods that may involve high-content memories, input signals from sensory devices, input signals from other mechanisms and/or their controls, and inputs from computers whose territory may cover an entire manufacturing plant". Third degree mechanization covers all power mechanisms under the complete control of humans; fourth degree is the first level with direct control by a human. The fifth degree includes powered mechanisms which are not under the direct control of a human operator but have been programmed at the outset. They are faster, easier to change, and more precise than fourth degree machines. Industrial robots are defined as all mechanisms with "fifth degree", or higher, level of automation though fourth degree are sometimes included. Sixth degree mechanisms are capable of holding several programs in memory. The seventh and eighth degrees cover the ability to change the operations by "inputs generated by other mechanisms and/or their controls". Although no industrial robot on the market yet meets the requirements, the American Machinist has defined a ninth degree the most important elements of which are tactile and visual sensors.

In a report on the industry published in 1974, Frost and Sullivan a U.S. consulting company, defined five generations of industrial robots numbered in half steps from 1.0 to 3.0.[1] The first generation includes industrial robots which are "programmable, memory-controlled, open-loop and several degree of freedom" machines. The next generation (labelled 1.5 by Frost and Sullivan) includes sensory controls (electro-optics, pressure, torque and force sensitive touch, and proximity and other special

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[1] "The U.S. Industrial Robot Market", Frost and Sullivan Inc., New York, June, 1974.

sensors). The controls gradually evolve through the generations to the highest level, level 3.0, which includes industrial robots equipped with "artificial intelligence".

The Frost and Sullivan report contains market forecasts for each generation of robot from 1976 to 1985. To make the forecasts compatible with other projections, the data for generations 1.5 to 3.0 have been combined leaving generation 1.0, pick-and-place robots and limited sequence manipulators, as a distinct category. In 1972, the Stanford Research Institute published a market forecast for industrial robots. The projection covered a ten year period from 1971 to 1981 and was segmented into "industrial robots" and "limited sequence manipulators", categories which are comparable to the above groupings from the Frost and Sullivan report.

In the Stanford study, average growth rates of 27 percent for the United States, 21 percent for Western Europe, and 35 to 37 percent for Japan were applied to the 1971 population of industrial robots. For limited sequence manipulators, the average growth rates of 48 percent for the United States, over 50 percent for Europe, and 30 percent for Japan were applied to the 1971 inventory.

A five year life cycle was assumed for both limited sequence manipulators and robots. For the United States and Western European markets, an average unit cost of $8,000 was assumed for limited sequence manipulators and $25,000 for industrial robots. Unit costs in the Japanese market were projected to decrease by 2 percent per year from a base cost in 1971 of $28,900 for industrial robots and $8,800 for limited sequence manipulators.

In all markets, the expected growth rates represent averages over the ten year planning period (1971 to 1981). These averages were used in this report to interpolate the sales volumes for the years between 1976 and 1981. Actual growth rates were projected to be lower than average in the first years of the planning period and higher in the latter years. The projected annual sales volumes for limited sequence manipulators, from 1976 to 1981, are presented in Table 6.2; the projected annual sales volumes for industrial robots are presented in Table 6.3.

Based on the projected sales volumes in Tables 6.2 and 6.3, the world market for limited sequence manipulators and industrial robots should increase from approximately $35 million in 1976 to $172 million by 1981. This includes sales of new units and replacement units.

The Stanford report also discussed several new concepts and design improvements which could be adapted to industrial robots. These include:

1. introduction of modular design.
2. product versatility.
3. improved integration to the environment.
4. improved reliability.
5. incorporation of self-diagnostic systems.
6. better servicing including spare parts support, training and provision of well illustrated and clearly written manuals.
7. more versatile software and provision for interchangeability between industrial robots.
8. general purpose gripper tools or provision for rapid changing.
9. moving target synchronization.
10. new marketing strategies.
11. application technology (design and development).
12. software support.

TABLE 6.2

PROJECTED ANNUAL SALES VOLUME BY GEOGRAPHIC AREA - LIMITED SEQUENCE MANIPULATORS [1]

MARKET AREA	Projected Growth Rate (%)	Annual Sales Volume ($ Millions)[2] 1976	1977	1978	1979	1980	1981
United States	48	$ 11	$ 16	$ 23	$ 34	$ 51	$ 75
Western Europe	50	2	3	5	7	11	6
Japan	30	6	8	10	13	17	22
TOTAL	-	$ 19	$ 27	$ 38	$ 54	$ 79	$113

1. data from "Industrial Robots: An Opportunity", Stanford Research Institute, Menlo Park, California, 1972.

2. approximations based on <u>average</u> projected growth rates. Actual annual sales volumes expected to be lower in <u>initial</u> years and higher in latter years than the average expected sales volumes shown.

TABLE 6.3

PROJECTED ANNUAL SALES VOLUME BY GEOGRAPHIC AREA - INDUSTRIAL ROBOTS[1]

MARKET AREA	Projected Growth Rate (%)	PROJECTED ANNUAL SALES VOLUME ($ millions)[2]					
		1976	1977	1978	1979	1980	1981
United States	27	$ 8	$ 10	$ 13	$ 15	$ 20	$ 25
Western Europe	21	3	4	5	6	7	8
Japan	36	5	7	10	14	19	26
TOTAL	-	$ 16	$ 21	$ 28	$ 36	$ 46	$ 59

1. data from "Industrial Robots: An Opportunity", Stanford Research Institute, Menlo Park, California, 1972.

2. approximations based on average projected growth rates. Actual annual sales volume expected to be lower in initial years and higher in later years than the average expected sales volumes shown.

The report recommends that improvements in any of these areas could help a company presently in the market to gain a larger share, or any company considering entry to obtain a place in the growing market. Many of the areas identified in the list match very closely the program outputs of the Shuttle RMS, particularly in the "skills" and "technology" categories.

The Frost and Sullivan report was completed in 1974. The market projection for industrial robots in the lower classifications is based on the estimated growth in investment in new plants and equipment and more specifically in automation equipment. Industrial robots are considered a subsector of the automation equipment market. The growth in capital investment for industrial robots is evaluated for each of the major industrial classifications.

The market projection for industrial robots of an advanced design was based on the size of the work force in 1970 in manufacturing industries and an estimate of the percent of this work force that could be replaced by the higher generation robots (20 percent of 19.4 million by 1984, or 3.9 million). An estimated market penetration of 1.5 percent by 1985 then was applied to the potential market of 3.9 million units. The result is an estimated shipment of 58,000 units between 1977 and 1985.

A summary of the market projections of Frost and Sullivan is presented in Table 6.4.

Some of the companies currently in the market claim that the sales volumes projected by Frost and Sullivan are not realistic. It is generally accepted that these early projections were high because industry, with some exceptions, was not receptive to the introduction of industrial robots. Other reasons discussed in an article on robots

TABLE 6.4

PROJECTED MARKET GROWTH FOR INDUSTRIAL ROBOTS IN THE UNITED STATES[1]

INDUSTRIAL ROBOT CLASSIFICATION[2]	1974[3]	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Generation 1.0	$ 7.5	$10.0	$12.4	$17.4*	$ 22.4	$ 32.3*	$ 42.5	$ 53.3*	$ 62.0	$ 94.5*	$ 127.0	$ 125.0
Generation 1.5 to 3.0	13.5	19.1	24.6	70.1	149.6	216.1	332.5	456.3	630.0	842.5	1050.0	1275.0
TOTAL	21.0	29.1	37.0	87.5	172.0	248.4	375.0	508.6	692.0	937.0	1152.0	1400.0

* interpolated

1. data from "The U.S. Industrial Robot Market", Frost and Sullivan Inc., New York, June 1974.
2. Generation 1.0 includes pick-and-place robots and limited sequence manipulators. All other generations include some degree of memory and sensory control.
3. actual sales.

appearing in Machine Design (November 27, 1975) included the difficulty of selling management on ways to increase productivity through efficient use of existing equipment at a time when the emphasis was on expansion, not efficiency. With the growing cost of labour, manpower shortages, improved safety standards, and a drive to improve productivity, market forecasts are once again sounding a growth market for industrial robots.

Theta Technology Corporation, another industrial market research company, has estimated lower sales volumes. The company projects world sales of $274 million by 1980 and $367 million by 1985. Both this projection and those made by Frost and Sullivan are considerably higher than the market forecasts for industrial robots made by the Stanford Research Institute in 1972. While the Stanford projections also were criticized after publication as being unrealistically high, the actual sales figure of $21 million in the U.S. in 1974, reported by Frost & Sullivan, exceeds the projection made at Stanford by 140 percent ($10 million, projected, compared to $21 million actual). In fact, the Stanford study projected a total world market of only $19 million.

For the year 1980, Stanford Research Institute projected a U.S. market of $71 million; Frost and Sullivan projected a market of $375 million, due largely to the introduction of the higher order industrial robots. If these are excluded, Frost and Sullivan projects a market of $125 million.

Therefore, in view of the actual sales of industrial robots during the past two or three years and the increasing pressures towards automation, the projections made by Frost and Sullivan for the U.S. market have been accepted for this study. For the rest of the world, notably

Europe and Japan, the Stanford Research Institute projections of industrial robots have been increased proportionate to the difference between the Stanford projections for the United States and those made by Frost and Sullivan in the same year. For the years to 1990 not covered by the Frost and Sullivan report or the Stanford study, a straight line projection has been used. The number of new sales in each year not covered by at least one of the studies was assumed equal to the average of the sales in the last three years for which data are presented. The market forecasts based on these assumptions are presented in Table 6.5 for each five year period from 1976-1980 to 1986-1990.

The market forecasts for limited sequence manipulators, or generation 1.0 industrial robots, made by Stanford exceed those published by Frost and Sullivan. Therefore, for the markets outside the United States, the Stanford projections have been reduced in proportion to the differences between the Stanford projections and those made by Frost and Sullivan for the United States market. For those years covered by the Stanford or Frost and Sullivan projections, the assumptions used to develop the forecasts are the same as those discussed previously for the industrial robot market projections (generations 1.5 to 3.0). The market forecasts are presented in Table 6.6 by five year periods from 1976-1980 to 1986-1990.

A market for limited sequence manipulators and industrial robots has not developed in Canada yet, though there are a few isolated applications. In an approach to the PAIT program in 1970, Hayes-Dana Limited of Thorold, Ontario, a manufacturer of automobile parts, estimated that 15 industrial robots could be used in their manufacturing processes. Applying the ratio of the number of workers per robot to the total worker population in their industrial classification, Hayes-Dana generated a market projection for over 800 robots, or, at $10,000 per unit, a Canadian market of $8,000,000 in one industrial classification.

TABLE 6.5

PROJECTED ANNUAL SALES VOLUMES FOR THE UNITED STATES, WESTERN EUROPE, JAPAN AND CANADA - INDUSTRIAL ROBOTS

REGION	PROJECTED MARKET ($ Millions) 1976 - 1980	1981 - 1985	1986 - 1990
UNITED STATES	$ 792.9	$4,228.8	$5,237.5
WESTERN EUROPE	300.3	360.3	360.3
JAPAN	660.5	860.7	860.7
CANADA	4.0	39.6	211.4
TOTAL	$1,757.7	$5,489.4	$6,669.9

- derived from Table 6.3 and Table 6.4.

TABLE 6.6

PROJECTED ANNUAL SALES VOLUMES FOR THE UNITED STATES, WESTERN EUROPE, JAPAN AND CANADA - LIMITED SEQUENCE MANIPULATORS

	PROJECTED MARKET ($ Millions)		
REGION	1976 - 1980	1981 - 1985	1986 - 1990
UNITED STATES	$127.0	$460.8	$577.5
WESTERN EUROPE	36.7	43.0	43.0
JAPAN	50.8	62.7	62.7
CANADA	3.0	6.4	23.0
TOTAL	$217.5	$572.9	$706.2

- derived from Table 6.2 and Table 6.4.

The normally accepted standards for estimating the Canadian market are 20 percent of the U.S. market developing three to five years later. Because the industrial climate in the U.S. is very similar to Canada and because the same pressures exist to consider introducing industrial automation, the same factors were applied to the estimated U.S. market in Tables 6.5 and 6.6, to estimate the potential Canadian market. Assuming a lag of five years, sales in Canada of industrial robots and limited sequence manipulators can be expected to increase from a nominal level of $7.0 million in 1976-80 to $46 million in 1981-85 and $234 million in 1986-90.

6.2 Marketing Considerations

Except for the support given by the Japanese, there is no evidence of government subsidies to companies in the industrial robot market either through grants or protective legislation.

In the industrial robot market, sales often are handled by licensing a company to manufacture the product in the country of sale. For example, Unimation, the world's largest manufacturer of industrial robots, has assigned licences to companies in many parts of the world. In Norway, Trallfa has awarded at least two licences to firms in Canada. Trallfa prefer to licence the technology to a company interested in a specific application (i.e. paint spraying) rather than to a company that manufactures and sells industrial robots. Perhaps it is because of these many licensing agreements that there seems to be little government intervention in the industrial robot market.

The structure of the market for industrial robots is different from any of the other three discussed in this report. The manufacturer of industrial robots sells directly to the customer. There are no intermediaries (except licencees) or government agencies in the chain. Of all the applications analyzed in this report, the market for industrial robots seems to show the closest link between the supplier and the customer.

The Stanford study lists six manufacturers who in 1972 controlled 100 percent of the market in the United States and Western Europe, and 86 percent of the market in Japan. The companies, and their reported market share in 1972, are listed in Table 6.7. Unimation dominates the world market, and particularly the U.S. market, since acquiring the licence for the U.S. to sell the Trallfa series of robots.

TABLE 6.7

MARKET SHARE BY MANUFACTURER AND GEOGRAPHIC AREA - 1972[1]

	UNITED STATES	WESTERN EUROPE	JAPAN
Unimation	75%	30%	31%
AMF	25	44	21
Trallfa	-	26	-
Fujikoshi	-	-	14
Ihsikawajima Harima	-	-	10
Mitsubishi Heavy Industries	-	-	10
Others	-	-	14
TOTAL	100%	100%	100%

[1] data "from Industrial Robots: An Opportunity", Stanford Research Institute, Menlo Park, California, 1972.

With sales beginning to increase, more companies are being attracted to the market. In 1975, more than 170 companies were reported to be offering over 200 models of industrial robots. The majority of these companies supply limited sequence manipulators, or "pick and place" robots, at a unit price in the $7,500 to $15,000 range. Only four companies, in the U.S. at least, manufacture multi-purpose, programmable, memory-controlled robots - Unimation Inc., AMF Versatran, Sundstrand Corporation, and Robotics Inc. These companies sell industrial robots in the unit price range of $15,000 to $25,000. The industrial market is certainly the most competitive of all the markets studied for this report.

6.3 Potential Market Penetration

For this study, an initial market penetration into the Canadian market of 30 percent, increasing by 10 percent in each five year period, was assumed. For markets outside Canada, zero penetration was assumed before 1980. After 1980, the market penetration is projected to be one-half of one percent for the last two planning periods. In the report prepared for Spar, a market penetration factor of zero was assumed in the analysis. However, when considering all of Canadian industry it is possible that a company in Canada may enter this area of the market. To reflect this possibility, an initial market penetration factor of 5 percent was assumed for the Canadian market, increasing to 10 percent by 1986. A low penetration factor was used because of the number of companies competing in this market. For other market areas, a penetration factor of one-half of one percent was assumed for all planning periods.

The market penetration factors are summarized in Table 6.8.

TABLE 6.8

ESTIMATED PENETRATION OF THE INDUSTRIAL MARKET FOR REMOTE MANIPULATOR SYSTEMS

MARKET APPLICATION	MARKET PENETRATION (%) 1976 - 1980	 1981 - 1985	 1986 - 1990
INDUSTRIAL			
Robots (Canada)	30.0	40.0	50.0
Robots (Other)	0	0.5	0.5
LSM (Canada)	5.0	5.0	10.0
LSM (Other)	0.5	0.5	0.5

LSM - limited sequence manipulators

6.4 The Potential Market (Industrial) and a Comparison with the Previous (1974) Trend Analysis

The application of the market penetration factors in Table 6.8 to the estimates of the total market in Tables 6.5 and 6.6 generates the total projected sales presented in Table 6.9. The potential market to 1990 totals $193.4 million. A comparison with the trend analysis completed in 1974 is presented in Figure 6.1.

One of the major reasons for the difference is the use of the Frost and Sullivan projections as a basis for the present analysis rather than the Stanford Research Institute projections which were used for the 1974 analysis. Also the present analysis includes the higher generation robots and provision for the Canadian market. All of these factors contribute to the difference in the two projections.

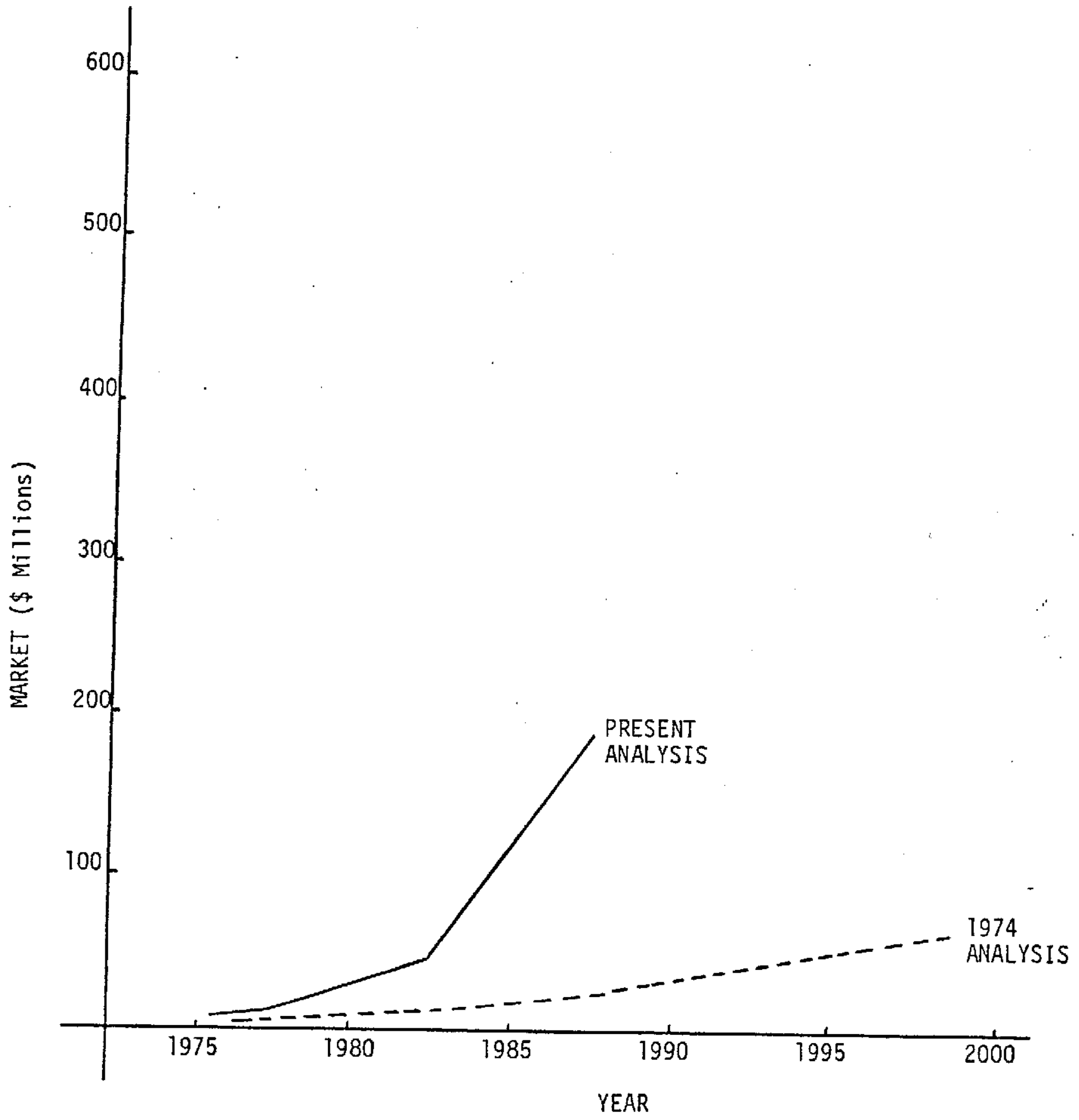
TABLE 6.9

PROJECTED SALES OF REMOTE MANIPULATOR SYSTEMS BY CANADIAN INDUSTRY TO THE INDUSTRIAL MARKET

MARKET APPLICATION	PROJECTED SALES ($ millions)		
	1976 - 1980	1981 - 1985	1986 - 1990
INDUSTRIAL			
Robots (Canada)	$1.2	$15.8	$105.7
Robots (Other)	0.0	27.3	33.4
LSM (Canada)	0.2	0.3	2.3
LSM (Other)	1.0	2.8	3.4
TOTAL	$2.4	$46.2	$144.8

FIGURE 6.1

PROJECTED CUMULATIVE SALES OF REMOTE MANIPULATOR SYSTEMS IN THE INDUSTRIAL MARKET BY CANADIAN INDUSTRY - A COMPARISON OF TREND ANALYSES



7.0 THE CANADIAN SECONDARY MANUFACTURING INDUSTRY

Sales of industrial robots in the United States, Japan, Sweden, and Norway have demonstrated the growing importance of this market. One of the major conclusions of this study is that the largest potential market for SRMS technology (apart from the space sector itself) lies in the area of production machinery and plant employed by secondary manufacturing industry. During the first 25 years of the post-World II era, Canada built a sophisticated and diversified industrial base. Manufacturing presently contributes some $35 billions to the Gross National Product (22% of GNP) and employs some 2,000,000 persons or 20% of the labour force.

Yet in 1975, Canadians imported some $26.5 billions worth of manufactured goods (equivalent to $1150 per capita!). As a result, Canada suffered a trade deficit of $10.2 billions in "End Products" which more than offset export earnings and was a major contributor to the record balance of payments deficit on Current Account of almost $5 billions experienced in 1975.

This is illustrated graphically in Figure 7.1 which shows a precipitous decline in the trade balance in End Products between 1970 and 1975. This deficit of $10.2 billions (which remained virtually unchanged in 1976) is symptomatic of some very fundamental problems in the manufacturing sector. In particular, it should be noted that the single largest element in the negative trade balance in End Products was a massive deficit for machinery of the order of $3.73 billions as shown in Table 7.1.

~~TABLE 6.9~~

FIGURE 7.1

TABLE 7.1

EXPORTS AND IMPORTS OF MACHINERY (1975)

	EXPORTS	IMPORTS	TRADE BALANCE
	(millions of dollars)		
FARM MACHINERY	541.3	1,077.3	-536.0
SPECIAL INDUSTRY MACHINERY	154.6	533.4	-378.8
FORESTRY EQUIPMENT	151.7	232.3	- 80.6
POWER EQUIPMENT	114.4	371.9	-257.5
MINING EQUIPMENT	108.6	221.1	-112.5
CONSTRUCTION MACHINERY	99.4	644.4	-545.0
STEEL MILL, METALWORKING AND MACHINE TOOLS	95.2	427.2	-332.0
INSTRUMENTS AND RELATED PRODUCTS	82.3	280.2	-197.9
MATERIALS HANDLING EQUIPMENT	75.0	156.1	- 81.1
PLUMBING, HARDWARE AND SMALL TOOLS	70.9	384.9	-314.0
PUMPS AND COMPRESSORS	44.2	173.7	-129.5
VALVES	38.0	119.1	- 81.1
BEARINGS	26.7	119.7	- 93.0
OTHER	84.4	675.5	-591.1
TOTAL	1,686.7	5,416.8	-3,730.1

SOURCE: MACHINERY BRANCH, IT&C

One important contributing factor to this situation has been the growing trend to transfer labour-intensive production off-shore to the "less-developed" countries. For example, between 1967 and 1973, imports of electrical products from LDC's increased by 800% and imports of machinery increased by 600%. This is a direct consequence of rising labour costs in Canadian manufacturing, and there is every likelihood that the trend will continue unabated for the foreseeable future.

In the higher technology products, labour productivity is still one of the decisive factors in determining international competitiveness. Here again rising labour costs combined with the dis-economies of small scale production runs have seriously eroded the competitiveness of Canadian secondary manufacturers.

In both cases, the only feasible solution would appear to be to adopt more efficient production processes involving the utilization of more fully automated machinery. The introduction of Computer-Aided Manufacturing and Robotics offers the only realistic possibility for overcoming the foregoing limitations which presently handicap Canadian manufacturing. Both of these areas are potential applications of outputs from the SRMS program viz "Robotics" utilizing the mechanics and control techniques of the SRMS system and "Computer-Aided Manufacturing (CAM)" utilizing the SRMS technology and computer software.

7.1 The Canadian Machinery Industry

Despite the relatively large size of its manufacturing sector, Canada has not developed a significant machinery industry. Indeed, Canada is the world's largest importer of machinery amounting to some $5.4 billions in 1974, surpassing even the United States!

The absence of an indigeneous machinery industry has had three adverse effects on the viability of Canadian manufacturing industry, viz: the adoption of new production technology has been seriously retarded; the introduction of new product innovations has been impeded; and Canadian industry has been denied the opportunity to compete in the lucrative world market for advanced industrial machinery.

An illustration of the backwardness of Canadian manufacturing industry is the tardiness with which numerically-controlled machine tools have been adopted. A recent survey published by "Canadian Machinery & Metal working" shows a total of some 700 N/C machines distributed amongst 233 firms. In other words, fewer than 1% of all manufacturing establishments are equipped with state-of-the-art machinery.

The conclusion seems inescapable that the establishment of an indigenous capability for the development and production of advanced industrial machinery is a prerequisite to the reversal of the present decline of Canadian secondary manufacturing. Potentially the development of Computer-Aided Manufacturing and Robotics technologies could provide the basis for establishing a viable indigenous machinery industry in Canada.

7.2 Computer-Aided Manufacturing

> "Customized production at mass production prices" means that if we use a computer-controlled production line for discrete processes in manufacturing we can, at mass production prices, have the diversification of products that we have only to date been able to have through very expensive custom work.
>
> Dr. Ruth Davis
> U.S. National Bureau of Standards

As noted earlier, the only feasible option for combatting the twin handicaps of low-wage competition and small-scale production inefficiencies would appear to lie in increasing the productivity of Canadian manufacturing through the adoption of advanced production technology. The use of general purpose machinery with computer control is particularly applicable to discrete parts production where recent studies have indicated unit cost savings of at least 25%.

The next stage of development for N/C machinery is the use of a central computer to control and schedule the operations of a series of N/C machines. The ultimate goal will be "Computer-Aided Management of Production" (CAMP) leading to the realization of the fully automated factory capable of performing the following functions:

i) Computer generated parts lists, vendor ordering, production scheduling and inventory control. More and more these are becoming real-time transaction oriented rather than batch systems.

ii) Computer controlled stacker cranes for automatic movement of material in and out of raw materials storage, work in progress inventory, and finished goods inventory.

iii) Computer controlled delivery of components to machining centres and assembly areas employing robotics.

iv) Direct computer control of numerically controlled machine tools, inspection, and automatic test equipment".

The technology developed for the operation and programming of the SRMS would form an excellent foundation for the development of CAM systems. Another dimension can be obtained through the use of computer-aided design (CAD) which can then be combined with CAM to create a fully integrated manufacturing system extending from the design phase through production to the assembly and delivery of finished products.

Amongst other things, the CAM system offers the following advantages which are directly translatable into cost savings.

- Increased utilization of machine tools and capital equipment
- Reduced delivery time
- Reduced inventory requirements
- Increased labour productivity.

Unlike production line automation of the past, which required product standardization and long production runs in order to offer attractive returns on the large capital investment required, CAD/CAM systems, by virtue of their flexibility, can be economically justified for short run batch production, and therefore represent a unique opportunity for smaller businesses.

At the present time there is very little Canadian activity in this field. The I.T.&C office of Science and Technology has identified the importance of CAD/CAM and is endeavouring to promote interest in its applications by Canadian industry. There is also a limited research capability in the Canadian Institute of Metalworking at McMaster University and the Department of Mechanical Engineering at the University of Waterloo.

As regards market potential, studies undertaken in 1973 by the University of Michigan forecast that, by 1984, 65% of all N/C machine tools would be computer controlled and that 25% of all machine tools would have adaptive controls. However, within the limited time available for this study, it has not been possible to assess the potential market for CAM systems in Canada, or the export possibilities.

7.3 Robotics

A very high proportion of manufacturing labour is concerned with materials handling including loading and unloading the machine and transferring the work from one machine to the next. Studies of machine shops operations have shown that barely 5% of the processing time is actually occupied with machining; the balance consists of transport and waiting time. Furthermore, less than 30% of the time on the machine is actually employed in metal removal.

Accordingly one of the most immediate ways for improving the productivity of both labour and machinery is to improve the efficiency of the material handling process through the introduction of industrial robots.

While the mechanics are relatively straightforward, precision machining requires exact positioning of the workpiece and accurate gauging of the machining operation. Therefore, it would appear that the SRMS control system and position sensor devices would find direct application in automated manufacturing systems.

8.0 CONCLUSIONS AND RECOMMENDATIONS

One of the key objectives in initiating the SRMS program was expressed in the following terms:

> "It is the aim of the Canadian government to establish in Canada an industrial competence in the high technology area of teleoperator systems and to develop an industrial capability in the design and manufacture of remote manipulation systems for export and domestic use."

Furthermore, the following specific goals have been stated:

> "To achieve for Canadian industry the status of unique supplier of advanced Remote Manipulator Systems for all environments."
>
> " To provide the technological sub-structure for operation in environments hostile to man such as those in deep oceans, in nuclear reactor plants, and in the high Arctic."

Understandably, the current efforts of both the government agencies involved in the SRMS program and the industrial consortium have been concentrated entirely on the primary goal of developing the SRMS hardware to meet the very demanding timetable of the NASA Space Shuttle program which requires delivery by June, 1979. However, if the corollary industrial benefits identified in the program objectives are to be achieved, it would seem advisable, having identified and analyzed several commercial market opportunities, to initiate action as soon as possible to adapt the SRMS technology to terrestial applications and to build-up the necessary technological and industrial infrastructure in both the 'producer' and 'user' sectors.

sales sales not market!

Four market opportunities for SRMS were analyzed for this study. The potential market, to 1990, for each application may be summarized as follows:

X

sales

Application of SRMS	Cumulative Projected Market to 1990
SPACE	$ 466.0 million
UNDERWATER	$ 14.8 million
NUCLEAR	$ 32.3 million
INDUSTRIAL	$ 193.4 million

The opportunities identified in the space market appear to be most appropriate for the members of the consortium assembled for the SRMS program. The development of remote manipulator systems for the nuclear market would seem to be the most appropriate spin-off for the industrial members of the consortium since the products, services and customers are compatible with their present interests.

The projections for the underwater market are so small that specific incentives to encourage another Canadian company to enter this market would be uneconomical. Canadian companies already supplying remote manipulator systems to this market can probably take advantage of the opportunities which will arise.

The market which would seem to be the most attractive for a Canadian company is the application of the SRMS technology to the manufacturing sector. The analysis of this market in the study was limited to a review of two reports written in the United States, one in 1972 and one in 1974. An estimate of the potential Canadian market was simply extrapolated from these two reports since so very little data was available. Also, no investigation was made of the process whereby the appropriate technology from the SRMS program would be transferred to a Canadian company which would manufacture and market products in this area.

The analyses and data presented in this report clearly demonstrate the importance of the industrial automation market to Canada and the potential applications of systems and techologies from the Shuttle RMS program. The questions remain, however, of whether or not Canadian industry will soon move to introduce industrial automation on any large scale and whether specific incentives will be required. These are questions which must be answered within the next few months.

One possible approach would be a three stage investigation. The major objective of this investigation would be to obtain more definitive information on the potential market in Canada. A Canadian company would have a difficult, if not impossible, task in developing export markets without also establishing a significant base of domestic sales.

The first stage in the investigation would be to make a better assessment of the opportunities in Canada. This assessment could be made by discussing the important elements involved in the decision of whether or not to introduce industrial automation with manufacturers in several industrial classifications and different regions of Canada. Some of the important topics which should be included in the discussions are;

- awareness of the present availability of industrial automation equipment.
- current knowledge related to,
  - capabilities
  - cost
    - initial purchase
    - operating costs
    - maintenance
  - life expectancy
  - training requirements
  - required support equipment/systems
  - versatility

- perceived advantages, disadvantages, and reservations
- relevance to present operations; possible application in 5 years; in 10 years.
- cost expectations (both expenditures and savings)
- considerations if a Canadian company manufactures and services the equipment,
    - competence
    - reliability
- experience with N/C equipment, if any
- incentives which may be required
- what information on industrial automation the company would like to have

However, even before answers to these questions are obtained, it would be necessary to consider appropriate options for acquiring the <u>present</u> technology in industrial robots, and other industrial automation equipment. For example, in the beginning, should existing products be imported or manufactured under licence?

While there are many testimonials in the literature on the savings realized by companies which introduced industrial robots, no detailed reports were discovered which analyzed the particular situation before and after, discussed the economic considerations, and presented the justification. Such analyses would seem to be particularly useful as background material for companies in Canada considering the acquisition of automation equipment.

Therefore, a useful step would be to prepare specific case studies illustrating the introduction of industrial robots. Companies in the United States, Sweden, and Norway could be approached to provide the necessary background data and information. Preparing the case studies could indicate other important areas for discussion with industrialists in Canadian industry. Also, the case studies could become a valuable marketing tool for any Canadian company which might elect to enter this market.

The final topic which should be investigated, given that there is a significant market opportunity, is to determine how this opportunity should be exploited? For example, is there a company in Canada which would be interested in entering the industrial automation market, given the proper incentives if necessary? Also, how should the SRMS technology be transferred to the prospective users?

Investigations in these areas should provide the necessary information required to validate the potential market in Canada and, if the potential market appears to be of sufficient size, to provide the foundation for a company in Canada to consider entering the market.

APPENDIX A

INVENTORY OF EXISTING SUBMERSIBLES

SEA BED VEHICLES

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM NO.	MANIPULATOR SYSTEM VISUAL SYSTEM
DEEP SEA BOTTOM SAMPLER	Deutsche Babcock & Wilcox	N.A.	N.A.	N.A.	sampling	N.A.	
SEA BED VEHICLE	Hagenuk Vorm Neufeldt And Kuhnke	N.A.	N.A.	N.A.	various	M	
JH 160 SHALLOW TYPE UNDER-WATER BULLDOZER	Hitachi Construction Machinery Co. Limited.	N.A.	N.A.	N.A.	leveling & grading, weeding & ditching		
JH360 UNDERWATER BULLDOZER	"	N.A.	N.A.	N.A.	"	M	
UNDERWATER BULLDOZER	Komatsu	N.A.	N.A.	N.A.	excavating, Digging	M	
RUM	SCRIPPS	N.A.	N.A.	N.A.	sampling	M	

SUBMERSIBLES - UNMANNED

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	
						NO.	VISUAL SYSTEM
ERIC	Direction des Constructions et Armes Centre d'etudes et de Recherches Techniques Sous Marines	1971	Ministry of Armament	N.A.	survey	N.A.	
TROIKA	"	N.A.	D.C.A.N.-C.E.R.T.S.M.	N.A.	photography	N.A.	
TELENAUTE	Institut Francais du Petrole	N.A.	N.A.	N.A.	photography & sampling	1	
PAP	Societe ECA	N.A.	N.A.	N.A.	exploration & recovery	N.A.	
UNDERWATER OBSERVATION BUOY	Deutsche Babcock & Wilcox	N.A.	N.A.	N.A.	observation	0	
DEEP SEA PHOTO & TV TOWING SYSTEM	Ibak Helmut Hunger	1974	N.A.	N.A.	mapping, manganese modules	0	
BAC-1	British Aircraft	1974	Institute of Geological Sciences	N.A.	survey & sampling	1	
MOBELL DIVING BELL MK11	Mobell Marine Development	1966	N.A.	N.A.	surveys, inspection, diver support		

SUBMERSIBLES - UNMANNED

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM NO.	VISUAL SYSTEM
UNMANNED SUBMERSIBLE VEHICLE	Recording Designo (EMI)	1968	N.A.	N.A.	photography, inspection	0	
SHRIMP	Reynolds International	1971	N.A.	N.A.	survey	0	
CURV III	U.S. Naval Civil Engineering Laboratory	N.A.	N.A.	N.A.	ordnance recovery	1	
ATLANT I	Atlantic Institute of Organization of Fisheries	N.A.	N.A.	Atlantic	fisheries research		
SCORPENA	Leningrad Hydrometeorological Institute - Undersea Research Lab	1971	USSR	N.A.	research; photography	0	
SEVER 1	Polar Institute of Fisheries & Oceanography	N.A.	USSR	N.A.	observation	N.A.	

SUBMERSIBLES - MANNED (TETHERED)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	
						NO.	VISUAL SYSTEM
DB-900 (UGLY TUGLY)	Verne Engineering	under constr.	Deep Diving Systems	Thunder Bay	N.A.	M	N.A.
GUPPY	Sun Shipbuilding & Dry Dock	1970	Sun Shipbuilding & Dry Dock	U.S. waters	charter	N.A.	N.A.

SUBMERSIBLES - MANNED (Page 1 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	
						NO.	VISUAL SYSTEM
PC-3B	Perry	1963	IUC	world wide	offshore oil	1	T.V.
Shelf Diver	Perry	1968	French navy	French waters	military	N.A.	N.A.
PC-8	Perry	1971	Intersub Ltd.	North Sea	offshore oil	2	N.A.
PC-3X	Perry	N.A.	Applied Research	Gulf of Mexico	research	N.A.	N.A.
TS-1	Perry	1971	P&O Subsea Ltd.	North Sea	offshore oil	M	N.A.
PC-5C	Perry	1971	Sub Sea Oil Services	N.A.	offshore charter	M	N.A.
PC-8C	Perry	1971	Sub Sea Oil Services	N.A.	offshore charter	2	N.A.
OPSUB	Perry	1972	Ocean Systems	N.A.	offshore charter	1	T.V.
VOL L1 (PC-15)	Perry	1973	Vickers Oceanics	North Sea	offshore charter	1	T.V.
DIAPHUS (PC-8)	Perry	1974	Texas A&M Univ.	Gulf of Mexico	research	1	N.A.
PC-14C	Perry	1975	U.S. Army (Kentron Hawaii Ltd)	Pacific ocean	retrieval	1	N.A.
L2	Perry	1975	Vickers Oceanics	North Sea	offshore charter	1	T.V.
L3	Perry	1975	Vickers Oceanics	North Sea	offshore charter	1	T.V.
PC-1201	Perry	1975	Intersub Ltd. (Northern Offshore)	North Sea	offshore oil work	2	T.V.
PC-1202	Perry	1975	Intersub Ltd. (Northern Offshore)	North Sea	offshore oil work	N.A.	N.A.
PC-16	Perry	under constr.	Intersub Ltd.	N/A	N/A	2	T.V.

SUBMERSIBLES - MANNED (Page 2 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	
						NO.	SYSTEM
PC-17	Perry	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
PC-1203	Perry	under const.	COMEX	N/A	offshore oil work	2	N.A.
PISCES I	Hyco	1966	Vickers Oceanics	North Sea	ordnance retrieval	1	T.V.
PISCES II	Hyco	1968	Vickers Oceanics	North Sea	offshore charter	1	T.V.
PISCES III	Hyco	1969	Vickers Oceanics	North Sea	offshore charter	1	T.V.
PISCES IV	Hyco	1969	DOE (Canada)	Canadian waters	research	2	N.A.
SDL-1	Hyco	1970	Canadian navy	Canada	N.A.	2	N.A.
PISCES V	Hyco	1973	Hyco	world wide	subsea survey	2	N.A.
AQUARIUS I	Hyco	1973	P & O Subsea	Canadian waters	offshore charter	1	N.A.
PISCES VIII	Hyco	1975	Vickers Oceanics	North Sea	offshore charter	1	N.A.
AQUARIUS II	Hyco	under const.	Hyco	N/A	inventory	2	N.A.
PISCES VII	Hyco	1975	Soviet Academy of Sciences	N.A.	research	2	N.A.
AQUARIUS III	Hyco	under const.	Hyco	N/A	N/A	2	N.A.
PISCES IX	Hyco	under const.	Hyco	N/A	N/A	2	N.A.
LEO I	Hyco	under const.	P&O Subsea	North Sea	offshore charter	2	N.A.

SUBMERSIBLES - MANNED (Page 3 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM NO.	MANIPULATOR SYSTEM VISUAL SYSTEM
PISCES VI	Hyco	under const.	Soviet Academy of Sciences	N/A	research	2	N.A.
TAURUS I	Hyco	under const.	P & O Subsea	North Sea	offshore charter	N.A.	N.A.
PISCES X	Hyco	under const.	Vickers Oceanics	North Sea			
PS-1 (NARWAL)	Perry Submersibles	N.A.	ACCESS	Arctic	under ice operations	0	
PS-2 (PC-8)	Perry Submersibles	N.A.	ACCESS	Arctic	under ice operations	0	N.A.
GISMER GRIFFON	Direction des Constructions et Armes Navales Centre d'Etude	1973	Direction des Constructions et Armes Navales Centre d'Etude	N.A.	survey, intervention, research, & retrieval of submarines (military)	1	T.V. & visual
ARCHIMEDE	DTCN	1961	CNEXO & French navy	N.A.	scientific work, exploration, search & rescue	3	T.V. (3)
ARGYRONETTE	Neyrpic-Alstham (hull)	1969	Institute Francais du Petrole (IFP)	N.A.	research, rescue, industrial (oil)	N.A.	
S.P. 3000	CEMA	1970	CNEXO	N.A.	research & exploration	N.A.	T.V. & visual
DIVING SAUCER 350	Recherches Sous-Marine	1959	Compagnes Oceanographique	French waters	research	N.A.	N.A.

SUBMERSIBLES - MANNED (Page 6 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYST	
						NO.	VISUAL SYSTEM
TOURS 110/50	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.
TOURS 180/50	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.
DSWS-300	Maschinenbau Gabler	develop	N.A.	N.A.	offshore oil & gas	N.A.	N.A.
TOURS 80 DCD/300	Maschinenbau Gabler	develop	N.A.	N.A.	pipeline inspection, cable maintenance and survey & sampling	N.A.	N.A.
TOURS 80 DCD/500	Maschinenbau Gabler	design	N.A.	N.A.	same as TOURS 80 DCD/300	N.A.	N.A.
TOURS 170/300	Maschinenbau Gabler	design	N.A.	N.A.	research, survey	N.A.	N.A.
TOURS 430/500	Maschinenbau Gabler	design	N.A.	N.A.	core sampling, inspection & survey	N.A.	N.A.
SHINKAI	Kawasaki Heavy Industries	1969	Japan Maritime Safety Agency	Japanese waters	research	1	N.A.
HAKUYO	Kawaski Heavy Industries	1971	Ocean Systems Japan	Pacific ocean	subsea inspection	1	N.A.
STAR II (Asherah)	General Dynamics	1963	Deep Water Exploration	Hawaiian waters	coral collection	1	N.A.
STAR III	General Dynamics	1966	N.A.	N.A.	N.A.	1	N.A.

SUBMERSIBLES - MANNED (Page 4 of 11)

						MANIPULATOR SYSTEM	
NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	NO.	VISUAL SYSTEM
SEA FLEA (SP 500)	SUD Aviation	1969	Recherches Sous-Marine	N.A.	N.A.	1	N.A.
CYANA	Centre de l'Etudes Marine Avancees (CEMA)	1969	CNEXO	N.A.	research	1	T.V.
GLOBULE	COMEX	1973	COMEX	Mediterranean	subsea cable burying	N.A.	N.A.
MOANA I	COMEX	1974	COMEX	Mediterranean	offshore oil inspection	N.A.	N.A.
MOANA II	COMEX	under constr.	COMEX	N.A.	N.A.	N.A.	N.A.
MERMAID I	Bruker-Physik AG	1970	Bruker-Physik	N.A.	underwater inspection, observation, pipeline survey, coral cracking	T.V.	
MERMAID II	Bruker-Physik	1974	IUC	world wide	repair of sub-marine structures, rescue	view-port T.V.	tools
MERMAID III	Bruker-Physik	under constr.	P & O Subsea Limited	North Sea	offshore charter	N.A.	N.A.
TYPE B-AT 2/2/200U (Worksub)	Bruker-Physik	design	N.A.	N.A.	N.A.	1	N.A.

SUBMERSIBLES - MANNED (Page 5 of 11)

						MANIPULATOR SYSTEM	
NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	NO.	VISUAL SYSTEM
UNDERWATER WORKBOAT	Deutsche Babcock & Wilcox AG	design	N/A	N/A	N/A		N.A.
BURKHOLDER I (formerly ARGUS I (TOURS 64 DGK/300)	Maschinenbau Gabler	1971	KFODC KNO FENG OCEANIC DEVELOPMENT CO. LTD.	Pacific Ocean	research; repair of structures, gathering oceanic products, survey	1	viewports
ANTONINO MAGLIULO (TOURS 66 DGK/300)	Maschinenbau Gabler	1972	SELMAR, ITALY	N/A	research; repair of structures, gathering, oceanic products, survey.	1	viewports
TOURS 66 BK/100	Maschinenbau Gabler	N.A.	N.A.	N.A.	N.A.	M	N.A.
TOURS 60 DC/300	Maschinenbau Gabler	N.A.	N.A.	N.A.	N.A.	0	N.A.
TOURS 68 DCD/100	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.
TOURS 70 DCD/300	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.
TOURS 73/300	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.
TOURS 170 DGK/100	Maschinenbau Gabler	design	N.A.	N.A.	N.A.	0	N.A.

SUBMERSIBLES - MANNED (Page 7 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	
						NO.	VISUAL SYSTEM
KUROSHIO II	Japan Steel & Tube Corporation	1960	Hokkaido University	Japanese waters	research (fisheries)	1	N.A.
NEKTON ALPHA	General Oceanographics	1968	General Oceanographics	U.S. waters	offshore charter	1	N.A.
NEKTON BETA	General Oceanographics	1970	General Oceanographics	U.S. waters	offshore charter	1	N.A.
NEKTON GAMMA	General Oceanographics	1971	General Oceanographics	N.A.	surveys	1	N.A.
ALVIN	Litton Industries	1964	Woods Hole Oceanographic Institution	Atlantic Ocean	N.A.	1	T.V.
DEEP QUEST	Lockheed Missiles & Space Co.	1967	Lockheed Ocean Lab.	Pacific	research	2	T.V. & visual
BEAVER MARK IV (ROUGHNECK)	North American Rockwell	1968	International Underwater Contractors (IUC)	world wide	offshore charter	2	N.A.
ALUMINAUT	Reynolds International	1964	Reynolds Submarine Services	N.A.	charter	2	T.V. & imports
SEA OTTER	Rheem Superior	1966	Can Dive Services	Western Canada	subsea inspection	1	T.V.
NEMO	U.S. Navy	1969	Southwest Research Institute	Gulf of Mexico	research	0	visual
DEEPVIEW	U.S. Navy	1971	Southwest Research Institute	Gulf of Mexico	research	0	N.A.
MAKAKAI	U.S. Navy	1973	Naval Undersea Center	N.A.	military	0	Nemo sphere
DEEPSTAR 2000	Westinghouse	1969	Westinghouse	world wide	offshore charter	0	N.A.

SUBMERSIBLES - MANNED (Page 8 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM	VISUAL SYSTEM
						NO.	
DEEPSTAR 4000	Westinghouse	1966	COMEX	North Sea (possible)	offshore oil	1	N.A.
GVIDON	All-Union Scientific Research Institute of Sea Fishing & Oceanography	N.A.	N.A.	N.A.	fisheries research	0	N.A.
SEVER-2 (NORTH-2)	State Design Institute of the Soviet Fishing Fleet	N.A.	Polar Institute of Fisheries & Oceanography	USSR	fisheries research	N.A.	N.A.
TINRO I	N.A.	1965	USSR Pacific Fish Research Laboratory	USSR	fisheries research	N.A.	N.A.
TINRO II	N.A.	N.A.	USSR Pacific Fish Research Laboratory	USSR	fisheries research	N.A.	N.A.
BENTHOS V	Lier-Siegler Corporation	1963	USSR	USSR	N.A.	1	N.A.
BENTHOS 300	Lier-Siegler Corporation	1963	USSR Institute of Fisheries & Oceanography	USSR	research	N.A.	N.A.
SEA RANGER 600	Verne Engineering	1972	Verne Engineering	N.A.	general	2	N.A.

SUBMERSIBLES - MANNED (Page 9 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTE	
						NO.	VISUAL SYSTEM
DOWB	General Motors	1968	Friendship S.A.	South America	N.A.	N.A.	N.A.
JOHNSON SEA LINK I	Aluminum Co. of America	1971	Harbor Branch Foundation	Florida	research	N.A.	N.A.
BEN FRANKLIN	Giovanola	1968	Horton Maritime	Vancouver	under refit	M	N.A.
AUGUSTE PICCARD	Giovanola	1964	Horton Maritime	Vancouver	under refit		
SSV	Kockums	design	Kockums	Sweden	submarine support	N.A.	N.A.
URV (Underwater Rescue Vehicle)	Kockums	under constr.	Swedish navy	N.A.	rescue	N.A.	N.A.
NEREID 330	Nereid N.V.	N.A.	Nereid N.V.	Netherlands	offshore charter	N.A.	N.A.
NEREID 700	Nereid N.V.	under constr.	Nereid N.V.	Netherlands	N.A.	N.A.	N.A.
NEMO 1	ACF Industries	1965	Seaborne Ventures	Atlantic & Caribbean	offshore charter (treasure, inspection)	2	T.V.
SEA EXPLORER	Sea Line	N.A.	Sea Line	Northwest U.S.	general charter	N.A.	N.A.
SKADOC 1000	Skadoc Submersible Systems	1971	Skadoc Submersible Systems	North Sea	offshore charter	1	T.V.
SEA RAY (SRD-101)	Submarine Research & Development	1968	Submarine Research & Development	Northwest U.S.	N.A.	2	N.A.

SUBMERSIBLES - MANNED (Page 10 of 11)

NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM NO.	VISUAL SYSTEM
PHOENIX 66	Sub Sea Oil Services	under constr.	Sub Sea Oil Services	N.A.	N.A.	N.A.	N.A.
SNOOPER	Undersea Graphics	1970	Undersea Graphics	Northwest Pacific	N.A.	1	N.A.
DSRV I	Lockheed Missiles	1970	U.S. Navy	world wide	rescue	M	N.A.
DSRV II	Lockheed Missiles	1971	U.S. Navy	world wide	rescue	M	N.A.
DSRV III	Lockheed Missiles	N.A.	U.S. Navy	world wide	rescue	M	N.A.
SEA CLIFF	General Dynamics	1968	U.S. Navy	Pacific	military	2	N.A.
TURTLE	General Dynamics	1968	U.S. Navy	Pacific	military	2	N.A.
TRIESTE II	Mare Island Shipyards	1946	U.S. Navy	world wide	military	N.A.	N.A.
DSRV IV	Lockheed Missiles	N.A.	U.S. Navy	world wide	rescue	M	N.A.
KITTREDGE K-250	Kittredge Industries	N.A.	Seaborne Ventures	Atlantic & Caribbean	treasure recovery, inspection, profiles	1	N.A.
"	"	N.A.	Alfred Ampol	N.A.	personal	N.A.	N.A.

SUBMERSIBLES - MANNED (Page 11 of 11)

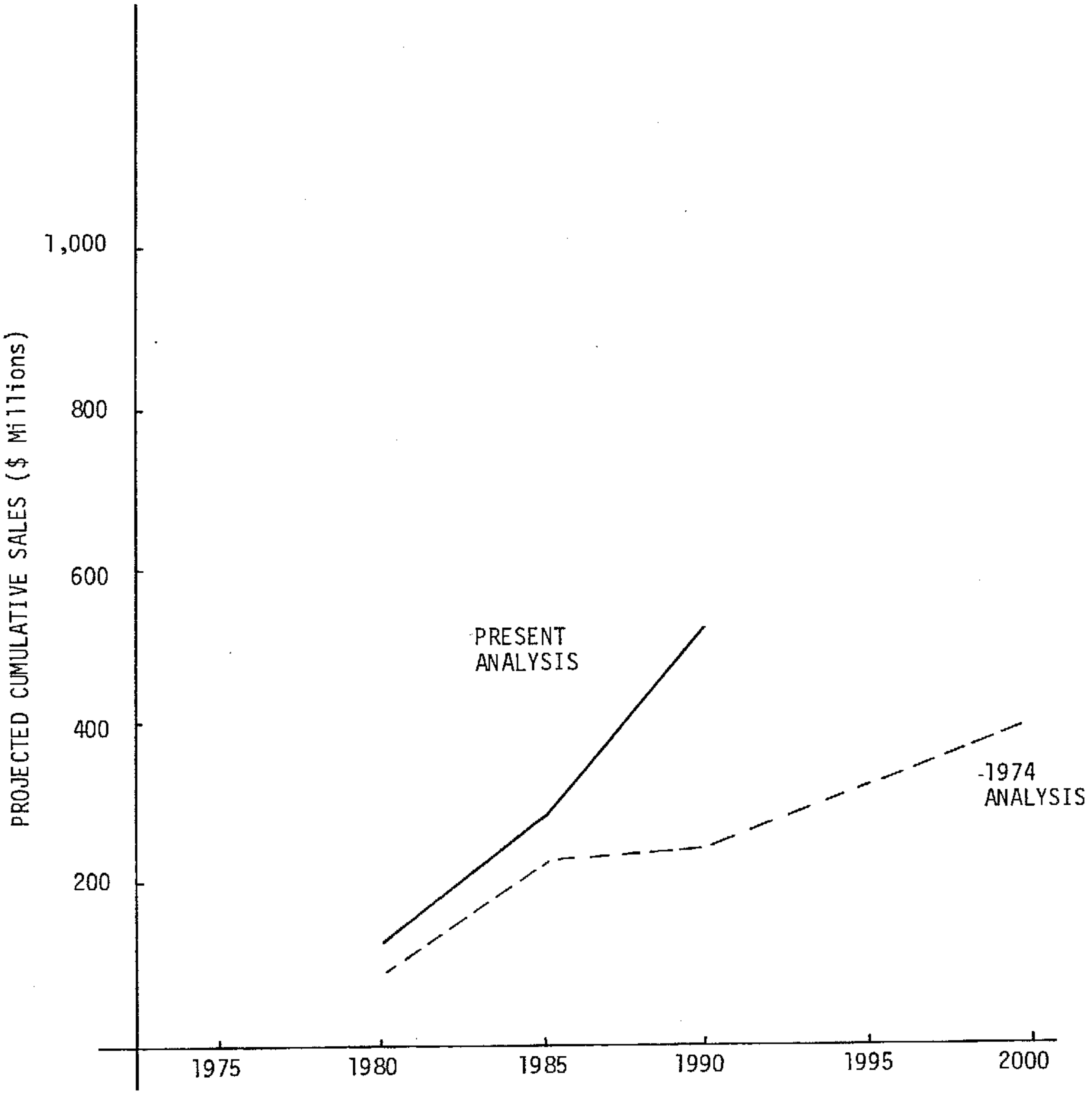
NAME	MANUFACTURER	YEAR OF CONST.	OPERATOR	WORK AREA	TASKS	MANIPULATOR SYSTEM NO.	VISUAL SYSTEM
KITTREDGE K-250	Kittredge Industries	N.A.	Richard Carbonne	N.A.	personal	1	N.A.
"	"	N.A.	Commercial Divers	Halifax	N.A.	N.A.	N.A.
"	"	N.A.	R. Dennis	N.A.	personal	N.A.	N.A.
"	"	N.A.	Grand Equipment Corporation	New Brunswick	N.A.	N.A.	N.A.
"	"	N.A.	B. A. Knauth	N.A.	personal	N.A.	N.A.
"	"	N.A.	Albert Leonard	N.A.	personal	N.A.	N.A.
"	"	N.A.	Master Divers	New Brunswick	N.A.	N.A.	N.A.
"	"	N.A.	Paul Piatonas	N.A.	personal	N.A.	N.A.
"	"	N.A.	Bob Tostenson	N.A.	personal	N.A.	N.A.
PRV-2	Pierce Submersibles	1975	Pierce Submersibles	Atlantic	prototype	M	N.A.
OSA-3-600	Giproryblflor Research & Design	?	USSR Ministry of Fisheries	USSR	fisheries research	1	N.A.

The reader is cautioned that the report is confined to:

- four out of a possible 100 market opportunities (Table 2.3),
- complete manipulator systems, not subsystems or components,
- fallout from Shuttle Remote Manipualtor System (SRMS) technology that exists at the present time among members of the SRMS industrial team, not necessarily manipulator technology existing in other groups, and
- data based on mid-1976 information.

FIGURE 3.1

PROJECTED CUMULATIVE SALES OF REMOTE MANIPULATOR SYSTEMS IN THE SPACE MARKET BY CANADIAN INDUSTRY - A COMPARISON OF TREND ANALYSES



3.4 The Potential Market (Space) and a Comparison with the Previous (1974) Trend Analysis

The estimates of market penetration which are summarized in Table 3.2 generate a projection of cumulative sales for remote manipulator systems in space applications of $466.0 million to 1990 (Table 3.3).

The projected sales exceed an earlier projection made in 1974 for Spar by P. A. Lapp Limited by approximately 100 percent. The two projections are compared in Figure 3.1. The major reason for the increase in the projected sales is the addition to the estimated market of more than $200 million in design and development contracts. Other contributing factors include an increase in the estimated unit price of a remote manipulator system for the Orbiter, from $6 million per unit to $15 million, the projected sales of special terminal devices on SPMS, the projected sales of SPMS to DOD, and the provision of training facilities and support personnel.

represent appropriate opportunities for other Canadian companies. The report prepared for Spar Aerospace Products Limited contains many references to information, financial data, and corporate strategies which are confidential to the company. Philip A. Lapp Limited, with the consent of Spar Aerospace Products Limited, entered into a contract with the Department of Industry, Trade, and Commerce, to prepare a revised report which would present useful information and statistics on the relevant markets for the remote manipulator technology while, at the same time, keeping confidential the financial information and strategies provided by Spar for the original report.

The four market assessments prepared for Spar discussed the present market and the potential applications of remote manipulator technology in some detail. The projections of potential market size on the other hand were limited to reviews of projections in the literature and simple extrapolations of factors and trends. The objective was to achieve a first approximation of the potential size of each market. The report proceeded to determine the approximate return on investment in each market and to present appropriate marketing strategies for Spar.

The sections covering estimated return on investment and proposed marketing strategies are excluded from this report. Instead, a section has been added which discusses the present status of the Canadian machinery market and proposes a methodology for collecting additional information and data on the one market area, industrial automation, which would seem, at this time to be the most appropriate for Canadian industry.

Four market opportunities for SRMS were analyzed for this study. The potential sales, to 1990, for each application may be summarized as follows:

Application of SRMS	Cumulative Projected Sales to 1990
SPACE	$ 466.0 million
UNDERWATER	$ 14.8 million
NUCLEAR	$ 32.3 million
INDUSTRIAL	$ 193.4 million

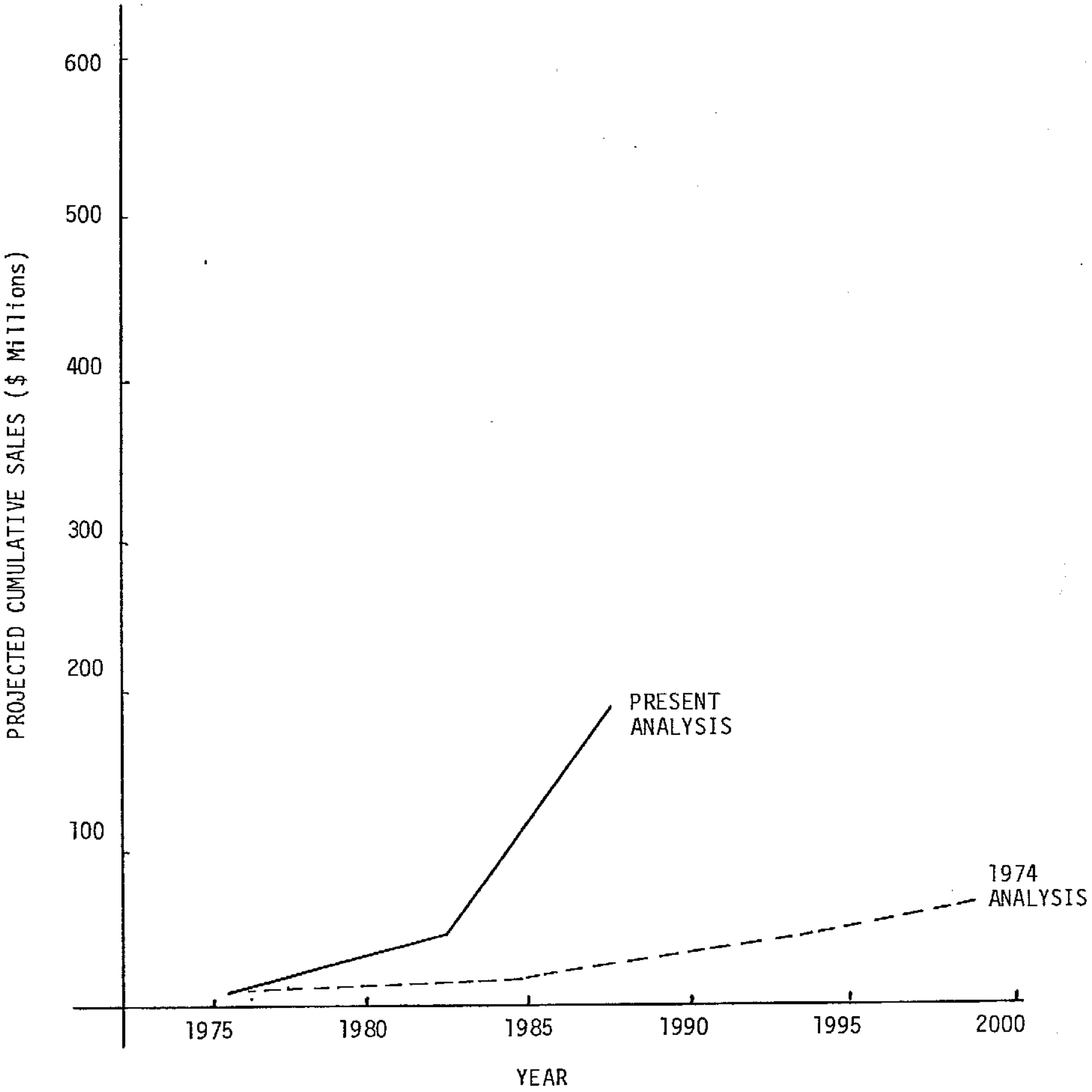
The opportunities identified in the space market appear to be most appropriate for the members of the consortium assembled for the SRMS program. The development of remote manipulator systems for the nuclear market would seem to be the most appropriate spin-off for the industrial members of the consortium since the products, services and customers are compatible with their present interests.

The projections for the underwater market are so small that specific incentives to encourage another Canadian company to enter this market would be uneconomical. Canadian companies already supplying remote manipulator systems to this market can probably take advantage of the opportunities which will arise.

The market which would seem to be the most attractive for a Canadian company is the application of the SRMS technology to the manufacturing sector. The analysis of this market in the study was limited to a review of two reports written in the United States, one in 1972 and one in 1974. An estimate of the potential Canadian market was simply extrapolated from these two reports since so very little data were available. Also, no investigation was made of the process whereby the appropriate technology from the SRMS program would be transferred to a Canadian company which would manufacture and market products in this area.

FIGURE 6.1

PROJECTED CUMULATIVE SALES OF REMOTE MANIPULATOR SYSTEMS IN THE INDUSTRIAL MARKET BY CANADIAN INDUSTRY - A COMPARISON OF TREND ANALYSES



6.4 The Potential Market (Industrial) and a Comparison with the Previous (1974) Trend Analysis

The application of the market penetration factors in Table 6.8 to the estimates of the total market in Tables 6.5 and 6.6 generates the total projected sales presented in Table 6.9. The potential sales to 1990 total $193.4 million. A comparison with the trend analysis completed in 1974 is presented in Figure 6.1.

One of the major reasons for the difference is the use of the Frost and Sullivan projections as a basis for the present analysis rather than the Stanford Research Institute projections which were used for the 1974 analysis. Also the present analysis includes the higher generation robots and provision for the Canadian market. All of these factors contribute to the difference in the two projections.

TABLE 6.6

PROJECTED MARKET FOR THE UNITED STATES, WESTERN EUROPE, JAPAN AND CANADA - LIMITED SEQUENCE MANIPULATORS

REGION	PROJECTED MARKET ($ Millions)		
	1976 - 1980	1981 - 1985	1986 - 1990
UNITED STATES	$127.0	$460.8	$577.5
WESTERN EUROPE	36.7	43.0	43.0
JAPAN	50.8	62.7	62.7
CANADA	3.0	6.4	23.0
TOTAL	$217.5	$572.9	$706.2

- derived from Table 6.2 and Table 6.4.

TABLE 6.5

PROJECTED MARKET FOR THE UNITED STATES, WESTERN EUROPE, JAPAN AND CANADA - INDUSTRIAL ROBOTS

REGION	PROJECTED MARKET ($ Millions) 1976 - 1980	1981 - 1985	1986 - 1990
UNITED STATES	$ 792.9	$4,228.8	$5,237.5
WESTERN EUROPE	300.3	360.3	360.3
JAPAN	660.5	860.7	860.7
CANADA	4.0	39.6	211.4
TOTAL	$1,757.7	$5,489.4	$6,669.9

- derived from Table 6.3 and Table 6.4

5.4 The Potential Market (Nuclear) and a Comparison with the Previous (1974) Trend Analysis

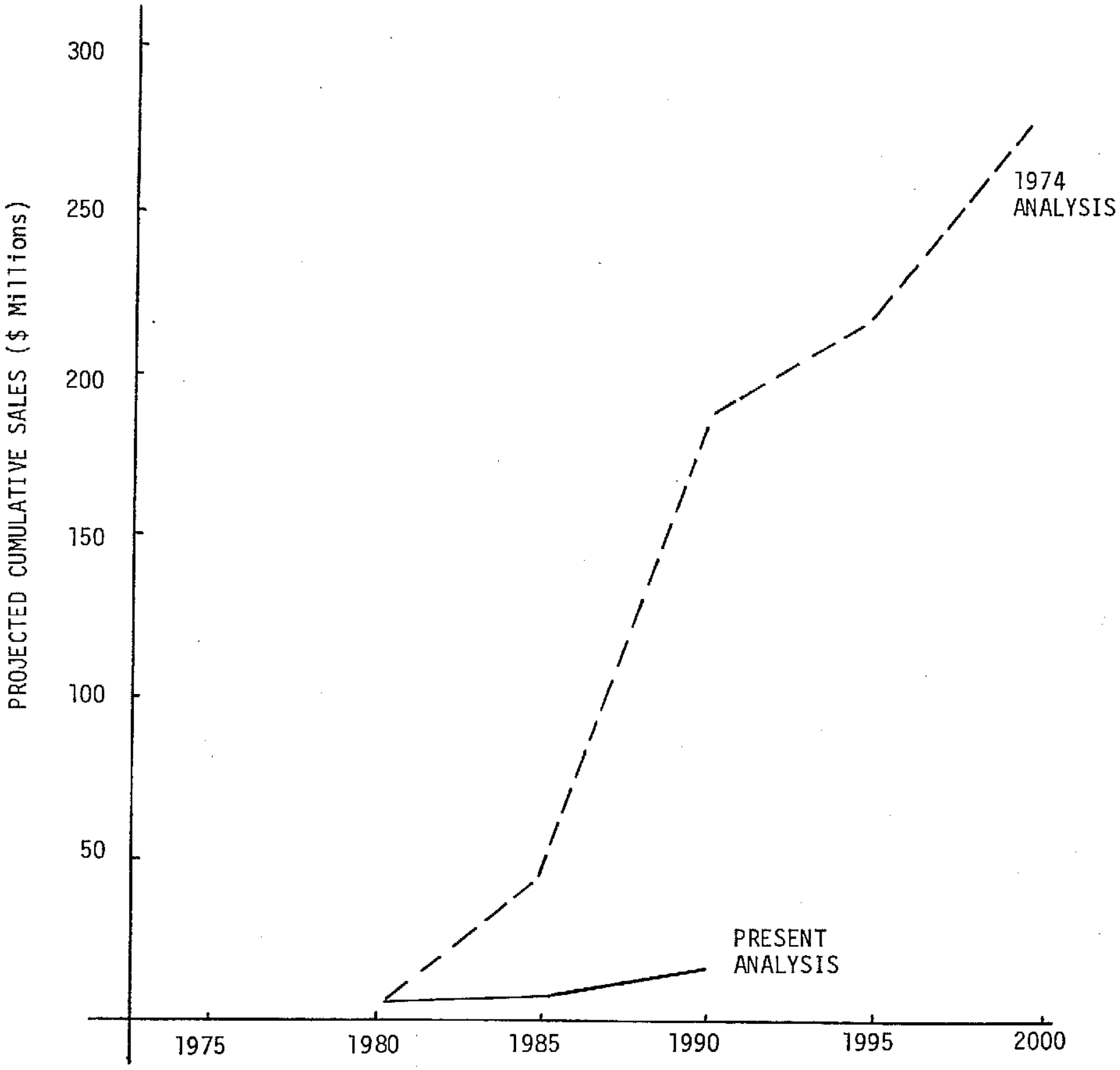
The penetration factors in Table 5.5 were applied to the market projections in Table5.4 to derive an estimate of the potential sales of remote manipulator systems by Canadian industry. The results are presented in Table 5.6. The data in this table show total potential sales of $32.3 million to the end of the 1980's. The total projected sales in the 1974 analysis were approximately the same. However, in the 1974 analysis, it was assumed that Canadian industry would concentrate on the market for fuel handling in nuclear power plants. Now, investigations for the present study reveal that, for several reasons, this segment of the market would be very difficult to enter.

However, the supporting markets such as the facilities in the fuel cycle, appear to show good sales potential. These markets were discussed in the 1974 analysis but not estimated.

Therefore, while the two market projections are similar they are in fact for different market segments. For this reason, a graphical comparison of the projected sales trends from the two studies would have no meaning and is not presented.

FIGURE 4.4

PROJECTED CUMULATIVE SALES OF REMOTE MANIPULATOR SYSTEMS IN THE UNDERWATER MARKET BY CANADIAN INDUSTRY - A COMPARISON OF TREND ANALYSES



4.4 The Potential Market (Underwater) and a Comparison with the Previous (1974) Trend Analysis

Applying the market penetration factors from Table 4.6, and the market share factors from Table 4.5, to the projected number of manipulators in Table 4.4, generates an estimated sales volume of $9.3 million to the end of the 1980's (summation of the subtotals in Table 4.7).

Because of the projected price of the remote manipulator systems and the extreme environmental conditions under which they will operate, a substantial market should develop for spares, and repair and overhaul capabilities. Canadian industry has experience in both these areas in the aircraft industry. For this reason, we have assumed that Canadian industry could obtain a significant portion of the spares, and repair and overhaul business in the underwater market. An estimate of the potential sales was developed by assuming that the market for spares and repair and overhaul would be 50 percent of the total sales of remote manipulator systems in the previous quinquennial. It also was assumed that Canadian industry could capture 50 percent of this business. The value of this segment of the market is shown in Table 4.7.

Including spares, and repair and overhaul, the total market is projected to increase from an average of $160,000 per year by 1980 to $1,600,000 per year by the end of the 1980's - a total market of $14.8 million.

This sales projection for remote manipulator systems for the underwater market is considerably less than a previous estimate made in 1974. The most significant reason for this dramatic reduction is that the previous analysis simply assumed that the necessity to exploit offshore resources, notably oil and gas, and the potential