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An Assessment of Undersea Teleoperators

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MIT Sea Grant
College Program

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Cambridge,
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ABSTRACT

Undersea teleoperators, general purpose submersible work vehicles remotely controlled by human operators, offer cost and safety improvements to scientific, military and industrial groups involved in underwater activities. This report assesses the current and near future applications of undersea teleoperators and competing modes of underwater intervention. It identifies the role of remotely operated vehicle systems and the implications on diving safety and underwater inspection of offshore installations. The current development trends for teleoperator systems are examined and federally supported programs are evaluated.

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GLOSSARY

ADS	Atmospheric Diving Suit
CCTV	Closed-Circuit Television
CIRIA	(UK) Construction Industry Research and Information Association
CNEXO	Centre National pour l'Exploitation des Oceans (France)
CTFM	Continuous Transmission Frequency Modulated (Sonar)
DDC	Deck Decompression Chamber
DLO	Diver Lockout (Manned submersible)
DOF	Degrees of Freedom
GRP	Glass Reinforced Plastic
HSC	(UK) Health and Safety Commission
MDU	Mobile Diving Unit (a Perry system)
MOB	Manipulation Observation Bell (a COMEX system)
NDT	Non-Destructive Testing
NOSC	Naval Ocean Systems Center, San Diego
OCS	Outer Continental Shelf
OSHA	Occupational Safety and Health Administration (US Dept.of Labor)
RDF	Radio Direction Finder
ROV	Remotely Operated Vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus
USCG	US Coast Guard
USGS	US Geological Survey
UARS	Unmanned Arctic Research Submersible System

1. INTRODUCTION

1.1 Purpose of this Study

This study attempts to determine how well teleoperators are fullfilling or can fullfill the safety and economic requirements for carrying out undersea activities in scientific, offshore oil and gas, and other application areas. With the known potential to develop this technology to a very advanced stage, it is important to determine to what degree this potential capability has already been developed.

There are a variety of interests involved in the system development. There are cost effectiveness criteria which may constrain the technical solutions. Any system must be able to compete on a straight cost-to-the-user basis, or it will not be commercially viable. For offshore underwater services there are also safety considerations that limit available solutions by requiring the activities to be carried out in a manner which has an acceptable safety level. This would apply to platform structural integrity considerations and diver safety considerations alike. There are no universal definitions of this acceptable level, but the safety considerations are reflected in operation costs.

The task content of many underwater activities are not fixed. They are subject to changes according to available technical means. This provides strong feedback to the underwater teleoperator developers and users.

Many of the above considerations are not quantifiable. Some of the questions concerning proven vehicle capabilities are answerable, for example on the basis of industry utilization rates. The near future plans of the industry (offshore operators, support equipment, and service suppliers) give some direction concerning the realistic problems and expectations for these systems. These factors together indicate the current and near future role of undersea teleoperators.

1.2 Definition of Terms

The undersea teleoperator is a flexible work device that allows a task to be carried out without requiring the human operator to be at the specific site at which the activity itself is taking place. The operator remains in a safe and habitable environment, away from immediate risks.

More precisely, teleoperators are defined to be general purpose submersible work vehicles controlled remotely by human operators and with video and/or other sensors, power, and propulsive actuators, with mechanical hands and arms for manipulation and possibly a computer for a limited degree of control autonomy. In a strict sense a manned submersible is not a teleoperator vehicle, but the attatched manipulators would be considered as teleoperators. In the offshore industry there are a variety of devices and systems which utilize teleoperator techniques or sub-systems. In the trade literature they are commonly referred to as remotely controlled vehicles, remotely operated vehicles, or unmanned vehicles. Although some of these devices do not have any type of manipulator or method for physically interacting with an underwater system, they may provide data or information via accoustic or video sensors, and are still considered to be teleoperators, of the simplest type. Also there are a host of systems which utilize a teleoperator on a manned submersible. There are many varieties of this arrangement suited for different activities. For this study, the manned submersible are systems considered as teleoperators but their use is treated in a less thorough manner.

1.3 Context of the Study

The inherent function or role of the undersea teleoperator is to assist a primary activity or function, be it installing a structure or device, or monitoring an action of another system. The teleoperator's value is only with relation to another activity. For this reason, this study attempts to avoid an approach which seems to have dictated the rationale for other studies of these systems. Other studies of submersibles and teleoperators have tended to concentrate only on the systems of interest, without any accounting of the evolving technology which the teleoperator is complementing. Instead, this study takes the view that analyses of the function and usefulness of the teleoperator must ask: What else could have achieved the same end product? What modifications have been utilized in similar situations? How do these contending solutions compare with the teleoperator?

The intent is to avoid letting the remotely controlled device be the only concern, in that it is only a convenient and timely means to an operational end. This perspective is most readily justifiable by looking at the newer offshore developments, that have avoided the use of large fixed structures, and which have an entirely different set of maintenance and inspection problems. This approach seems to better accomodate the "ambient" conditions and reduce the need for intervention activities at depth. The teleoperators' role assisting in offshore sctivities has been examined here, rather than as an end product by itself.

The method for assessing the technology for this purpose is to describe the technology which it must complement and with which it must compete. The function of the teleoperators as systems themselves is considered, but the dynamic or evolving aspect of the role of teleoperators is the determinant for understanding their current status.

1.4 Method

The assessment was carried out in the following manner. First a literature survey was made concerning; (1) the development of OCS resources, primarily with regard to the technology and methods involved; (2) the manned and remotely operated vehicles of all types (towed, bottom crawling, etc.); (3) the various groups within the US Federal government who have been involved in the development of the teleoperator technology. Regulatory agencies with use for teleoperators were identified and contacted.

The industry and governmental groups involved with the technology were contacted, and groups with a future potential utilization of the devices, such as deep ocean mining ventures. In an attempt to reflect the structure of the offshore oil and gas industry, the author contacted reprerentative companies from the following general sectors and the various regulatory or advisory groups involved with these sectors:

Offshore operators (with full or partial interests in major fields):
- operations divisions
- research and development divisions

Offshore design/construction firms (major structures):
- structural design, and installation groups

Offshore system design firms

Offshore underwater service firms providing diving or remotely operated vehicle services:
- operations personnel including saturation divers, vehicle operators

Teleoperator designers and manufacturers

US regulatory agencies, concerned with offshore structures, pipelines, and diving

Oil companies involved with deepwater drilling/production systems

US Naval laboratories engaged in research with underwater systems, primarily those with teleoperator involvement

UK and Norwegian regulatory and research agencies involved with offshore/underwater technology, structures, diving, etc.

By speaking with a representative selection of persons, an insight was gained into the needs for the teleoperators and related systems, the way by which the technologies are developing, and the anticipated development trends. Based on these conversations (for the most part by telephone and through correspondence) and the current literature, the author was able to obtain information on the developments and use of teleoperators.

Problems, Difficulties, Limitations

There are major drawbacks with this study. One is that it is an academic study and it differs in the point of view of an active service company or operator which have "real-world" cost and option perspectives. These companies tend to have an outlook (also cited by Busby), which is centered on their day-to-day operational or hardware problems. They generally have their hands full with this sort of work and do not have the resources or interest to be concerned with long-term development. This causes them to be less than familiar with developments outside their own activities or their competitors'.

Another problem is the lack of reliable data. From field operators to service companies, there is a lack of processed or correlated data on most operations taking place above and below the waterline. Many companies have not kept accessable records (or would not pass this information on) concerning the costs for previous contracts or the breakdowns on where operational costs may be attributed. Although most operating personnel did not have hard data, estimates were easy to obtain. Much of this was estimated percentages, etc., but this type of information appears to be fairly reasonable, although difficult to document precisely.

A third problem with this study is proprietary information. Many companies were very open regarding their work and cost data. However, some major firms were not willing to discuss jobs or costs, and were engaged in contracts that could not be discussed, for their client's sake. The most advanced systems, when commercially available, are generally not public information (especially long lead time prototypes, etc.) and are often still being sold. Because the competition for this type of equipment is on the basis of its advanced abilities, this capability question is a very private matter. Unfortunately this information was not usually available for discussion purposes.

A final area of important difficulty lay with unique conditions in the current status of teleoperator development. This is a rapidly evolving technology, and the use of these vehicles is changing on a yearly basis. Much of the accounting for the private utilization of these devices is reported after the summer season of activity on the North Sea. As figures presented later in this report indicate,there were a large number of sales of fairly sophisticated vehicles, during 1978/1979, the practical results and uses of which have yet to be reported. These activities, along with the introduction of other new equipment which they complement for drilling activities, etc., will result in changing utilization patterns for this technology since it relies on creative and adaptive applications.

1.5 Organization of this Report

Section 2 describes the different systems available for underwater intervention. The users of the systems are identified. The scientific, military, and minor industrial applications of underwater systems are examined.

Section 3 provides a detailed analysis of the tasks and activities that are performed underwater in support of the development of offshore oil and gas resources. There is an emphasis on inspection related activities, reflecting the high potential for future use of remotely operated systems for this work. The secondary factors in the determination of system choice are identified. Table 3.5 summarizes the factors that are important in the selection of systems for offshore operations, and identifies the systems now used.

Section 4 examines the capabilities of the different systems and makes comparisons between them. The costs of using the different means of access, divers, manned submersibles, and the remotely operated vehicles, are compared. The cost for performing a typical offshore job, a pipeline tie-in, are determined, and the relative costs of this are examined showing the high costs of surface vessel requirements. The current levels of system utilization are determined for the different systems. This includes some projections of current trends for remotely operated vehicle substitutions for divers. The modes of access for underwater inspection tasks are considered along with the predicted needs for this work on the North Sea.

Section 5 assesses the safety implications of the current and near future use of remotely operated systems. This includes a discussion of some of the recently established safety lessons from the North Sea area, especially regarding the relation of depth and risk. The US, UK, and Norwegian regulatory requirements for diving safety are compared and the relation between diving safety regulations and the substitution of remotely operated systems is examined.

Section 6 attempts to show the relation between the needs for underwater inspection of structures, the availability of remotely operated systems, and the upcoming changes in the US OCS regulations that will require underwater inspections.

Section 7 identifies some of the more important aspects of the current development of undersea teleoperator systems. It focuses of the trends for specialization, and the orientations of different groups involved in development. The needs of the different users, including Federal agencies, are identified with relation to the current programs. The lack of efforts aimed at shallow water systems are noted. The Navy and scientific requirements for un-tethered systems are contrasted to the needs for development of cheaper, more capable tethered systems. The present role of the Federal government in the support of development programs is identified. The need for commercialization of more sophisticated systems is outlined.

Section 8 summarizes the conclusions of the earlier sections. The current roles of the different undersea teleoperator systems are related to the cost and safety justified needs for increased utilization and continued development.

2. UNDERSEA TELEOPERATOR APPLICATIONS AND REQUIREMENTS

2.1 General Considerations

This study attempts to establish some of the cost and safety determiners of the use of undersea teleoperators. First it is necessary to establish the underwater activities to which underwater systems are applied and the desired results of these activities. This has been accomplished in the following manner. The users of the various systems are identified. The various types of vehicles and underwater intervention systems are identified. A group by group study is made of the users, their methods, and motivations for use of alternate systems. This is used as a basis for establishing the types of capabilities systems are required to have for different application areas.

Three groups of activities are useful for assessing the use of teleoperators and underwater work systems: First are those activities that are not presently carried out by undersea teleoperators (UTs), but are presently accomplished by using a diversity or a particular type of means such as divers, manned submersibles, or purpose-built systems, that offer different cost or safety factors than if done by teleoperators. The second group of activities are partially or wholly carried out by teleoperators, but not with satisfactory levels of capability or quality of results. This would apply to many present day tasks where an ROV is used for part of the activity or operates at too slow a rate to be satisfactory. The third group of activities are those not in demand today, or not in the present capability of any available system. This would include system support for future ocean therman energy conversion plants (OTEC), or support of deep ocean mining activities.

A major element that has been missing from previous studies of undersea teleoperators, or ROVs (remotely operated vehicles), is the context of system use, the secondary task considerations. In order to consider some of the users concerns that determine the choice of the mode of underwater access, this study details the users and their activities. It then uses this information to determine the cost and safety aspects of the various systems. There are many reasons why some systems which appear to be feasible, safer, and cheaper methods for accomplishing tasks than others, are not used. These reasons are not apparent by themselves. By presenting a qualitative analysis it is possible to gain a broader consideration of the problems that are beyond just the access or work system choice.

2.2 Identification of Users, Systems, and Activities

2.2.1 Users

The utilization of undersea teleoperators is spread among a variety of interests. The most convenient identification is by the users' application area. These may be identified as industrial, military, and scientific/research, in the order of their decreasing utilization rates or activity levels.[1] By far the major user of all of the different underwater systems is the offshore oil and gas industry. Other industrial users are limited, or developing, or are not in areas of water depths that require the use of systems more sophisticated than surface diving techniques.

2.2.2 Types of Underwater Systems

Figure 2.1 indicates the variety of vehicles, methods, and modes of

FIGURE 2.1 TYPES OF CURRENT AND PLANNED SUBMERSIBLE VEHICLE SYSTEMS

	MANNED	UNMANNED	HYBRID
TETHERED	Submersible Diving Chamber (SDC) (for ambient-pressure divers) Atmospheric Diving Suit (ADS) -Anthropomorphic -Semi-Anthropomorphic (mid-water) Mobile Diving Units (MDU) Mobile Diving Units with Diver Lockout capability	Remotely Operated Vehicles (ROVs) -Free-swimming -Towed -Bottom Crawling Load Delivery Devices (LDD) (e.g. SPIDER)	Manned or Remotely Operated option (e.g. WRANGLER)
UN-TETHERED	Conventional Manned Submersible Manned Submersible with Diver Lockout capability Diver/swimmer delivery vehicle	Robot Vehicles Surface Interactive Vehicle (SIV) ROV-Deployed Un-tethered vehicle (e.g. ROVER)	—
HYBRIDS	Free-swimming: with Tethered or Un-tethered option (e.g. MANTIS)	-	—

access that are in use by the various groups which have activities to be carried out underwater. The approximate depth range in which these systems are capable of operating are given in Figure 2.2. These numbers reflect present or generally agreed-upon limits for each system. Some illustrations of representative systems for each type are given with other data in Appendix A, B and C.

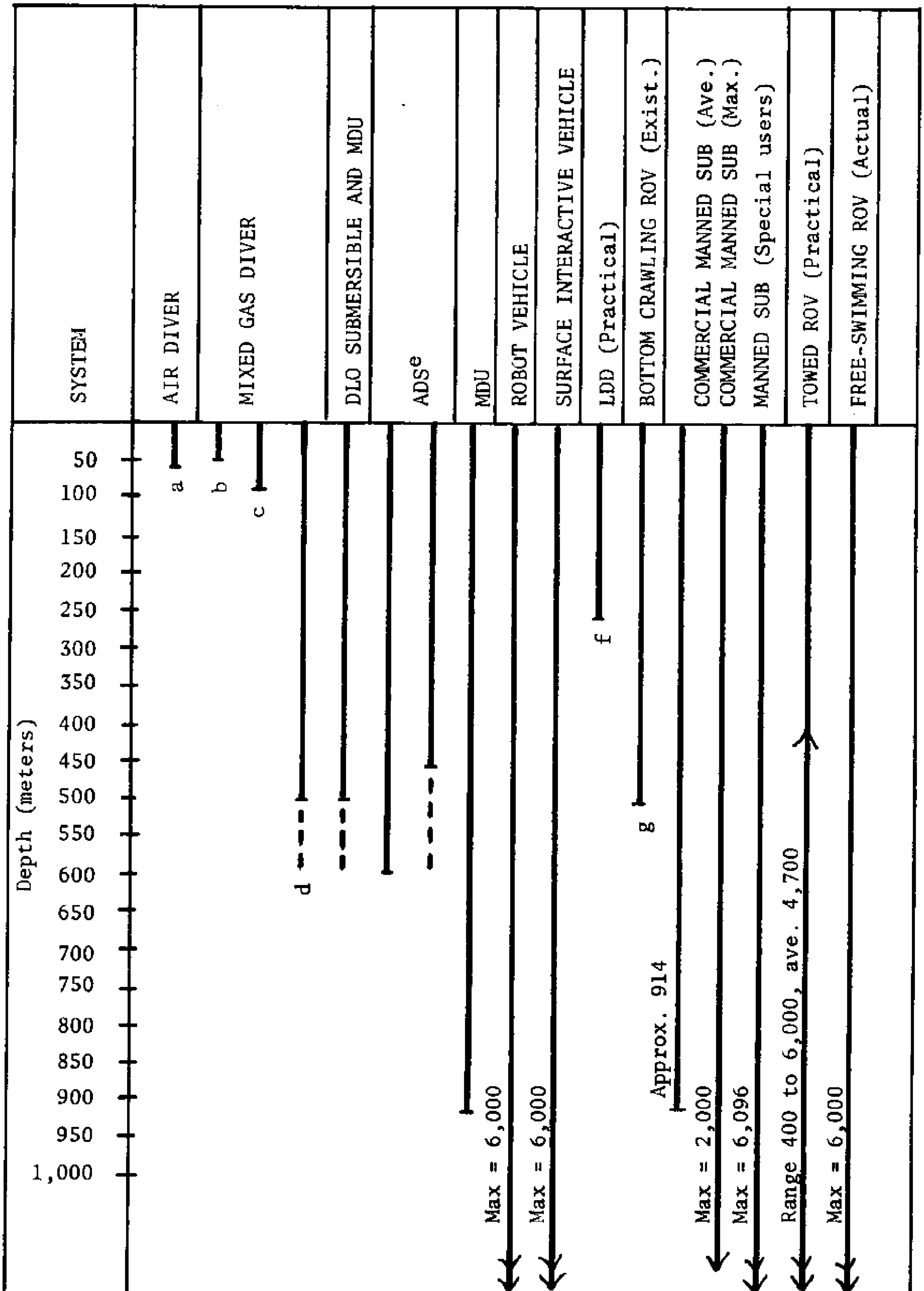
The categories of the work performed for the three user sectors are given in Table 2.1, where the systems or vehicle categories used correspond to the following four types of remotely operated vehicles which have been identified by Busby.[2] These four classes only include the so-called Remotely Operated Vehicles (ROVs). Together they comprise only a sub-set of the total choice of undersea systems, both manned and unmanned. However because the primary interest is to establish the degree of usage of undersea teleoperators, the ROVs are the prime concern, and especially the free-swimming tethered and un-tethered types, which are referred to as ROVs. The four classes of ROVs are:

I Tethered, Free-Swimming Vehicles: Powered and controlled through a surface-connected cable. Self-propelled, capable of 3-dimensional maneuvering, remote viewing through a closed-circuit television, with some or no capability for manipulation (teleoperation may apply to the vehicle or a manipulator arm).

II Bottom-Crawling Vehicles: Powered and controlled through a surface-connected cable. Self-propelled by drive wheels or similar traction devices, capable only of maneuvering on the bottom or on a structure, with remote viewing, possible manipulation.

III Towed Vehicles: Powered and controlled through a surface-connected

FIGURE 2.2 CURRENT DEPTH RANGES FOR UNDERWATER ACCESS MODES



(cont'd)

Figure 2.2 (cont'd)

NOTES:

(a) US Coast Guard regulations limit commercial diving operations with surface-supplied air to depths of 190 FSW (except for limited duration dives of 30 minutes or less bottom time to 220 FSW).

(b) UK and Norwegian diving regulations require use of a closed bell for all dives in excess of 50 meters.

(c) US Coast Guard regulations require use of a closed bell (SDC) for all dives in excess of 300 FSW (91.5 m), with few exceptions.

(d) Although dives have been carried out to depths in excess of 500 meters, this is the estimated practical limit for mixed gas diving. At these depths (~1,600 FSW) the increase in the work of breathing (due to gas density) reduces the divers capability to about 50% of his capability at the surface .

(e) The ADS WASP is rated for 610 meters. The practical limit for operations of ADS has been estimated at about 450 meters due to psychological stress limits in case of loss of umbilical. However, they have been used as deep as 1,440 feet to date.

(f) Reported device (SPIDER) works to 250 meters; practical limitations undetermined.

(g) Max. operational capability is Kvaerner-Myren's trenching system rated to 500 meters.

TABLE 2.1

ROV WORK CATEGORIES

TETHERED, FREE-SWIMMING VEHICLES

Industrial	Military	Scientific/Research
Inspection Monitoring Survey Diver Assistance Search/Identification Installation/Retrieval Cleaning	Inspection Search/Identification Installation/Retrieval	Inspection Survey Installation/Retrieval

BOTTOM CRAWLING VEHICLES

Industrial	Military	Scientific/Research
Bulldozong Trenching Inspection Manipulation	Drilling Trenching	None

TOWED VEHICLES

Industrial	Military	Scientific/Research
Survey	Search/Indentification/Location Survey Fine-grained Mapping Water Sampling Radiation Measurements	Geological/Geophysical Investigations Broad Area Reconnaissance Water Analysis Biological/Geological Sampling Bio-assay Manganese Nodule Survey/Study

UNTETHERED VEHICLES

Industrial	Military	Scientific/Research
None	Conductivity/Temperature/Pressure Profiling Wake Turbulence Measurements Under-ice Acoustic Profiling	Bathymetry Photography

Source: R.Frank Busby, Remotely Operated Vehicles, Sponsored by US Dept. of Commerce, Contr. No.03-78-603 (US Government Printing Office, Washington DC, August 1977) p 4.

cable. Propelled by surface ship, capable of maneuvering only forward and up/down by cable winch. Remote viewing through closed-circuit television (CCTV).

IV <u>Untethered Vehicles</u>: Sėlf-powered, controlled by acoustic commands or by preprogrammed instructions. Self-propelled, capable of maneuvering in 3 dimensions. Current systems do not include remote real-time viewing capability.

The differentiation of the vehicles or devices may also be done on the basis of the method by which they are controlled. The control/ communications alternatives for remotely manned vehicles are shown in Figure 2.3.

The classification and analysis of remotely operated and manned vehicle has been carried out in detail and accuracy by NOAA, and the sources for much of the hardware details used in the following pages are given in the accompanying references.[3]

Because of the diverse character of vehicles and systems it makes little sense to try to decide which manufacturer's vehicle is better than which other, although vehicle class comparisons may be made for capability determination. The same problem occurs in a different way for comparison between system capabilities, e.g. comparing the diver to a sophisticated ROV. There is not yet any good basis for performance comparison, since the capabilities of the two are so vastly different. By thorough examination of the tasks to be carried out, it is possible to determine suitability of use, on the basis of an aggregate of use-influencing factors, such as cost, safety considerations, reliability, adaptability, and other measures of suitability. These determine the over-all poten-

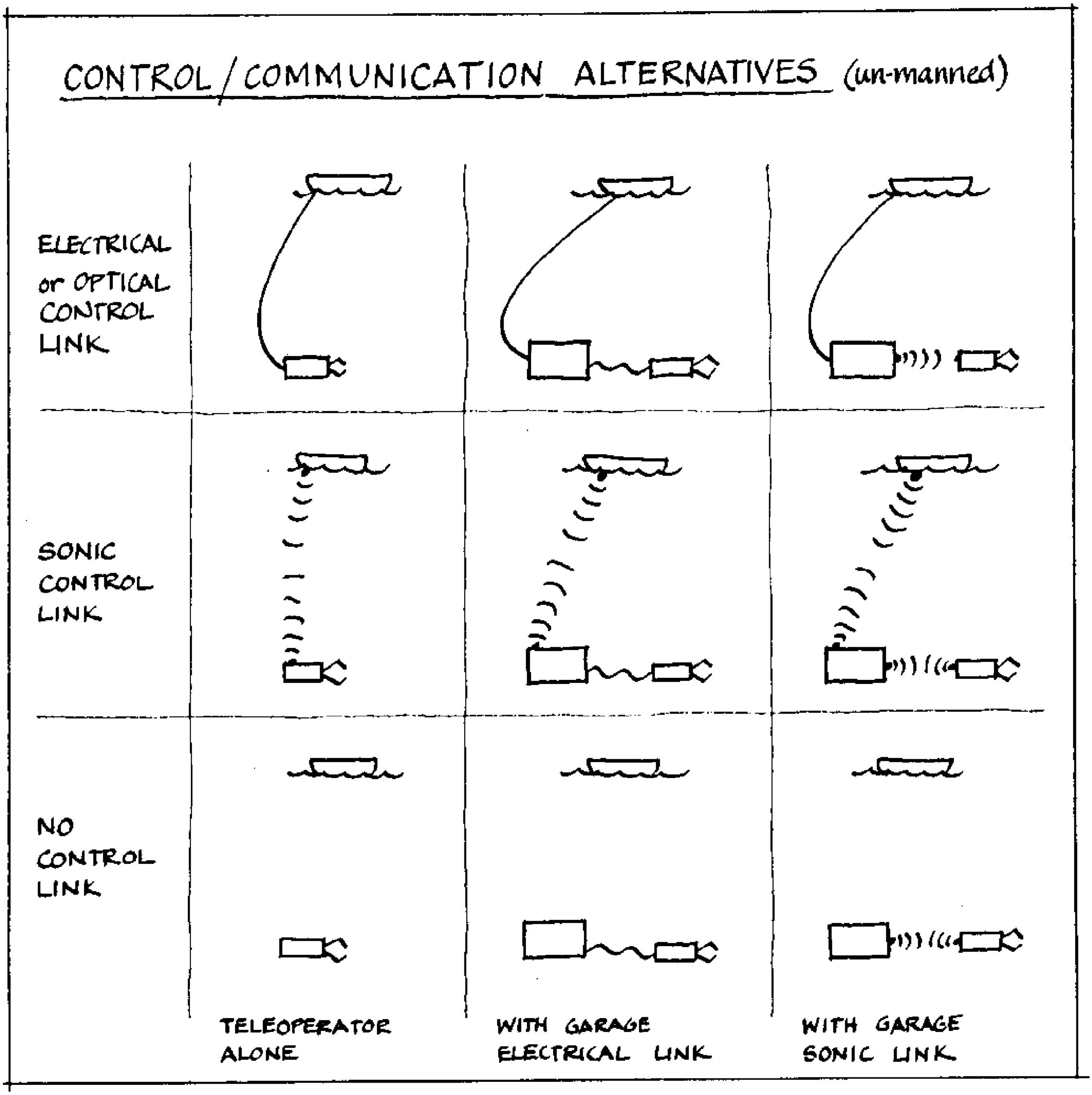


FIGURE 2.3 COMMUNICATION ALTERNATIVES for unmanned vehicles will be important in determining the trade-off between human and computer control. The particular configuration will, of course, depend on task to be accomplished, operating depth, size, speed, power source, duration, etc. The above matrix classifies alternative forms of communication: 1) with the surface ship (if any); 2) with an intermediary "garage" (if any).

Source: Sheridan and Verplank, Human and Computer Control of Undersea Teleoperators, (Cambridge 1978) tials for utilization and provide the basis for the assessment of the undersea teleoperators.

2.2.3 Activities Utilizing Underwater Systems

In order to accurately reflect the uses of the various types of vehicles/systems, it is necessary to examine the activities carried out by the industrial and scientific users. Although Table 2.1 does contain the disaggregated tasks and work categories it must be augmented by information on the users normal methods for task accomplishment and long-term work interests. The following sections of this section are intended to provide this information, which is applicable to most of the systems, but includes undersea teleoperators. The view given on utility of systems are based on present systems and present opinions. This is especially true for the scientific users where future ROV usage is anticipated but not currently occuring. These sections follow the previous user category definitions of industrial, military, and scientific users.

2.2.4 Scientific Applications/Users

The scientific groups which are largely responsible for the development of the vehicles and their sub-systems are on the whole distinct from the research and oceanographic community. Some of the devices or systems have been developed by the scientific interests in support of their primary pursuits but most of the vehicles employed by the scientific community have been built by vehicle developers, except those test-bed type devices or teaching/learning projects. The exceptions to this would be some of the towed devices such as th ANGUS built by the Woods

Hole Oceanographic Institution or the ROV PHOCAS. Also two of the early North Sea ROVs, the CONSUB and the SNURRE, were originally developed for scientific applications.[4] In addition to the users of the vehicles, there are vehicle development orientated groups, such as those at the Naval Research Laboratory, CNEXO, MIT, Jet Propulsion Laboratory, etc., which are involved with vehicle or sub-system development, but who do not have any or have little actual in-house vehicle utilization or needs.

Among the non-military scientific users, are the following disciplines:[5]

<u>Oceanography</u>

- Biological
- Chemical
- Geological
- Physical
- Geophysical
- Environmental/Ecological

<u>Archaeology</u>

<u>Fisheries</u>

- Research
- Operations

<u>Related Fields</u> (requiring testing/experimentation in the ocean).

The persons and groups working in the above areas of interest have not traditionally had the budgets or organizations with the capability for the support of sophisticated underwater vehicles, manned or un-manned. For this reason most of these users have developed a spectrum of devices that may be deployed from the surface which retrieve, measure, sample

TABLE 2.2 OCEAN EXPLORATION AND SURVEY PARAMETERS

Parameter	Air-Sea Interface (10 to -10m)	Upper Water Column (-10 to -500m)	Lower Water Column (-500 and deeper)	Bottom	Sub-bottom
1. Ice	x				
2. Sea-swell-surf	x				
3. Surface meteorology	x				
4. Surge	x				
5. Tides	x				
6. Currents	x	x	x		
7. Hydrodynamic forces	x	x	x		
8. Noise	x	x	x		
9. Salinity	x	x	x		
10. Temperature	x	x	x		
11. Turbidity	x	x	x		
12. Biomass	x	x	x	x	
13. Nutrients	x	x	x	x	
14. Oxygen	x	x	x	x	
15. Pollutants	x	x	x	x	
16. Electrical		x	x	x	
17. Bathymetry				x	
18. Geomorphology				x	
19. Rheology				x	
20. Engineering properties				x	x
21. Geochemistry				x	x
22. Geology				x	x
23. Geothermal				x	x
24. Physical properties				x	x
25. Radiometric				x	x
26. Gravety					x
27. Magnetics					x
28. Seismic					x

Source: H.R. Talkington, Remotely Manned Undersea Work Systems at Naval Ocean Systems Center. Naval Ocean Systems Center, San Diego CA 1978.

or monitor on a remote basis. These devices are characterized as simple and reliable. This would include the various oceanographic instruments that have been designed for sampling, sensing, and analysis of the subject of interest. Table 2.2 lists the parameters of interest to the scientific community, on a depth basis. It should be noted that the measurement of most of these parameters does not require an active man-machine interface, and may be carried out on a remote sensing/sampling basis. Most of the parameters are of interest on a long time-span basis, and are probably, in the long run, a data and sensing apparatus concern. The potential for use of ROVs in these cases is in the placement/retrieval or monitoring of such devices.

The use of undersea teleoperators and the use of conventional manned submersibles for the scientific community has been the subject of a previous study.[6] In addition to this source NOAA has compiled some data on the method by which some of the tasks that require real-time human interaction are carried out. The following list indicates the areas in which submersibles are utilized:

Mission Categories:[7]

Oil Industry

Coral Harvest

Training or Test

Inspection

Fisheries

Salvage

Biology

Geology

Mission Categories (cont'd)

Pollution

Cable Bury

This indicates potential areas of use for ROVs, where it may be possible for the ROV to replace the manned submersible. The subject of interchange-ability will be discussed later in this section, but it should be noted that most oceanographers do not utilize underwater vehicles at all, and use surface operated methods. The cost and logistics of manned submersibles, which were available before any useful ROVs, has limited their use to a few prestigious or specialized institutions, which will likely be the case for the use of ROVs by the oceanographic community in the future.

In general actual cost of operation and maintenance for the use of a manned submersible is not high in absolute terms. An example of the cost relative to alternate use problem, one source pointed out that the cost of the insurance premium for only a dozen or so archeological dives of a submersible equalled the entire cost of a small excavation on land, and this forced the eventual sale of a university's vehicle.[8] At first glance this may indicate a potential area for use of possibly cheaper ROVs. But the economics of the use of ROVs, especially by the science community are not so easily justified, because of funding and capability considerations.

A discussion with a member of the Woods Hole Oceanographic Institution (WHOI) ALVIN operating staff shows some of the considerations of science users of underwater vehicles. In general the choice of utilization of manned submersibles is economic in a limited fashion. The vehicles are not able to cover the areas required that are necessary for the identification of major geological structures and in the case of the WHOI work, the ALVIN is used in conjunction with the ANGUS, which is a towed instrumentation sled/cage affair. The ANGUS is towed over a large area at relatively high speeds and takes photo records of the features. After an area of specific features or interest (biological, geological, or other) is identified, the manned submersible ALVIN is then utilized for a detailed examination and sampling/observation/documentation work.

The use of ALVIN is limited to a small fraction of the scientific investigations that WHOI makes, and is heavily subsidized by Navy assistance, for vessels, personnel, and actual construction and hardware.

The potential use of sophisticated ROVs in the place of manned submersibles in the scientific community does yet not seem to be widely considered, and is possibly not yet feasible dueto the needs of these applications to have the man in the process. The use of towed devices is considered to be the broadest used ROVs, but the use of tethered free-swimming vehicles (ROV) was not planned by any of the scientific organizations contacted.

Part of the problem is financial. The original cost of an ROV with substantial capabilities for manipulation is generally very high. The smaller "eye-ball only" vehicles are costing somewhere around $100,000 to $400,000. These vehicles have only minimum (if any) capabilities for performing any type of tasks, apart from observing, usually with black and white CCTV only. In addition to the vehicle cost there are also operating costs, including insurance, personnel, spare parts, and support vessel costs. Although the figures for original costs of hardware are lower than for a manned submersible (which may be on the order of $1 million) the operating costs are similar, and the performance characteristics are not comparable. The "observation-only" ROV is limited to just that-real-time video on the surface with recording and maybe photo recording of events over a limited area. In contrast to these highly maneuverable ROVs there are much less expensive devices such as the ANGUS or similar, which may provide the types of data of interest to the scientist, without the close maneuverability, but with a much better large area potential. Also much of the data desired is obtained by accoustical means, such as side-scan sonar, which is by itself adapted to towing behind a vessel. Ship time productivity becomes important for large area projects, and low-cost ROVs do not have any type of speed capacity, unless of the towed variety.

For missions requiring manipulation, there are ROVs with manipulator capacity nearly on the order of submersibles, but the cost of such systems present problems. In general the safety of a manned submersible is considered "good" and improving. (This is discussed in more detail in Section 5 on safety).

The cost-capability questions become dominant. The larger more capable ROVs with two or three manipulators, (but not force feedback) cost on the order of $600,000 to $1 million for the complete system. These vehicles are of a size and complexity that require almost the same capability (cranage, manpower, etc.) as a manned sub, but do not offer any major savings when capabilities are considered.

Some of these dis-economies of ROVs may stem from the small amount of use an ROV would have in the science area, compared to the volume of work presented by the offshore oil and gas user. But also the method by which the costs are paid merits examination

Although the un-manned submersible may offer a possible savings to the overall problem solution, the cost to the user may not reflect this. In the scientific community the cost of operating the manned submersible is not always paid by the user. The University National Oceanographic Laboratory System (UNOLS) has been set up to assure that all academic institutions have access to the Federally supported national facilities, including ships, the ALVIN submersible, and other facilities. In this case the ALVIN is supported by a tripartite agreement between the Navy, the NSF, and NOAA.[9] An indication of the cost of the operation only (excluding purchasing/amortization) of the ALVIN system (support vessel, crew, etc.) in 1977, when it was maintained in only limited operation, was approximately $1,000,000. (1977 dollars)[10] The cost to the user of the manned submersible ends up as less than for an ROV, and this appears to be the situation today. There have been suggestions that the cost of an ROV should be handled in a similar manner (i.e. by block funded lease), but there has been no information found on the outcome of this proposal.[11] These kinds of non-economic considerations tend to distort any justifications for the use of the ROVs, of the more capable types, in the scientific community.

The use of manned submersibles by the scientist for deep-water work is a valuable tool. Table 2.3 indicates the different users of the ALVIN submersible.

TABLE 2.3 APPROXIMATE ALVIN USAGE BY USER CATEGORIES
(including 1979 partial and planned uses)

Geologists		
Hard rock	25%	35%
Sediment	10%	

TABLE 2.3 (cont'd)

Biologists		
Benthic	30%	30%
Mid-water	0%	
Geochemistry (Zero prior to 1977, but currently growing)		15%
Geophysical (Seismic, microseismic, local gravity, and magnetic studies)		10%
Engineering		5%
Miscellaneous		5%

Source: Conversation with William Marquis, WHOI, July 11, 1979.

The actual tasks carried out by the submersible include follow-up on towed instrument records and surface activated systems to correct interpretations, direct sea-floor sampling, in-situ measurements (e.g. gradient magnetometer, etc.), and visual observation with photo/video documentation. The use of the ALVIN manipulator at depth is a major reason for utilizing the sub. It allows versatility in the mechanical sampling, due to the presence of the human operator. This allows the execution of diverse tasks (when subsequent missions are compared) which are not generally repetitive. The changing missions require re-configurations of apparatus used by the manipulator, which lend themselves better to a manipulator with the human operator at close quarters.

No task analysis was available for the ALVIN and a source stated that most of the equipment used and manipulated is mission/purpose-built and re-fit for each mission. Also it was noted that almost all of ALVIN work is done on the bottom, with very little mid-water work. The mid-water tasks are generally carried out by surface ships. This contrasts with most ROV systems which are designed to be operated in mid-water situations although capable of bottom work.

The ALVIN does represent an extreme cost and capability for manned submersibles. One source commented that the utilization of a vessel such as the ALVIN for oceanographic needs would probably never exceed one or two vehicles nationally. This same oceanographer commented that a high capability ROV would be subject to the same limitations, i.e. only a vehicle or so per coast since further general funds are not available for Federally sponsored operations.

A less expensive and more conventional manned submersible used for scientific/teaching missions, is the DIAPHUS. This two-man submersible with a depth capability of 365 meters is more representative of what is generally required for continental shelp investigations. (This contrasts with ALVIN's 4,000 meter capability and use on mid-ocean ridges, etc.). This vehicle is operated by the Department of Oceanography at Texas A&M, and has been utilized by marine biologists and geologists.[12] Its applications are on the border between feasibility of use of an ROV instead of a sub. Because of the low cost of the vessel (quoted as $160,000 which is apparently due to cost of the vessel be paid by other parties also) and the low operating costs of the sub, on the order of $1,600/day plus mob/demob, this vessel may be contrasted with the ALVIN. The operation is of course exceptional from a commercial point of view, but reasonable from a research institutions view in that; (1) the vessel is totally paid for; (2) the pilots are not employed full-time in this operation; (3) the system is very simple (from a navigation aid and data handling point of view); (4) the system is small (a PC-14 sub) and operates in a calm area, lessening support vessel specifications; and (5) no profit motive exists. It is a limited depth vessel that avoids the high operations costs that plagued the very sophisticated and now de-mobilized submersibles that were produced in the late 1960's. These subs were costing on the order of $15,000/day plus support, and were not in need by the oil and gas industry at the time, a factor which helps to keep submersibles mobilized even when not fully employed, and provides some opportunity for peripheral users to have use of the submersibles.

The scientists' use of a manned submersible or of an ROV is predicated on the need for detailed information at a depth. The reason for not using the other surface controlled techniques such as corers, grabs, dredges, hook-and-line fishing, spear fishing, rotenone poisoning, observation and photo by SCUBA divers, and underwater television is sometimes a matter in increased opportunities for viewing strata and biota directly or being able to observe or sample for a longer duration than say SCUBA or mixed gas diving permits.

Data presented by Palmer show good cost/area characteristics of a manned submersible compared to a SCUBA swimmer.[13] In the case presented it is found that for extended missions at depths as shallow as 20 meters, that a manned submersible offers the most economical approach to surveying. On the other hand the use of ALVIN for deep-sea survey is less efficient than other means (towed ROVs) due to speed limitations over large areas. The case presented by Palmer implies that the manned submersible is preferable for missions on the continental shelf involving assessment of waste disposal sites.

A further classification of users of submersibles in the scientific community would be on the basis of the depth ranges of interest. This basically separates the deep-ocean groups from the coastal and continental shelp interests, and provides some differences in operating criteria, for both ROV and manned submersible potentials. As stated previously there is not a large market for manned submersibles in the science community, and there is not yet any significant level of ROV usage reported. Limited use of ROVs by groups in the US, Norway, Finland, and Canada has been reported, but this appears to be on an irregular utilization basis.[14,15]

One documented use of a ROV for scientific ends has been reported by the EPA Radiation Source Analysis Branch, Office of Radiation Programs. The EPA made use of an un-manned submersible during two surveys, the 1974 and 1975 Farallon Islands surveys. For three other more recent surveys made in 1976 (Atlantic), 1977 (Pacific), and 1978 (Atlantic), they have utilized manned submersibles, in particular the ALVIN and the PISCES VI.[16] Although general performance characteristics of ROVs are discussed in a later section of this report, it may be noted that the EPA has commented that they can cover more area on the bottom with a manned submersible, and they prefer not to rely on attached cables for visualization and control. Additionally they experienced difficulties with the electrical system of the CURV III when more than 1,000 meters of umbilical were paid out and catenary action was a problem. Also they reported that they have been able to survey to greater depths with the ALVIN than was possible (at that time) with un-manned vehicles. The economic considerations of this work are not clear, since the specific costs to the user of the different methods is not known and not in general a reflection of real costs, since both the CURV III and the ALVIN are funded via the Navy.

Use of manned submersibles in the deep-ocean does not appear to have a growth potential and there have been many recent advances in the surface deployed methods/techniques which will further inhibit growth of utilization of ROVs or subs. Navy oceanographic interests have a strong influence on all the funding and work carried out in this area and are generally in line with civilian interests. (Navy ROV use does not reflect this in general, since the active sections of the Navy have different missions than other ROV users, as discussed in section 2.2.5 of this report). A representative of the Office of Naval Research indicated that the current and near future Navy interests are to develop more data on the horizontal variation of ocean properties (as opposed to the traditional vertical quality variations). This will entail the use of new families of expendable devices that are used only once and offer considerable increases in surface vessel efficiencies, due to avoidance of retrieval and the amount of time required to wait for a sensor package to return to the surface. Other developmental work being carried out at Naval laboratories include air deployed devices and devices which utilize buoy telemetry systems, with satellite transmission. These systems also avoid the excessive use of surface vessel capability, at a cost estimated by one source to be between $5,000 to $8,000 per day.[17] These data gathering methods are spin-offs from the various air-deployed devices developed by the Navy such as the "Sonodiver" and "Sparbuoy" both of which were used for sampling ambient noise at depths to 6,500 meters and 100 meters respectively with sensor output recorded,and later the device is located by RDF transmission. These devices are primarily designed for the Navy signature collection system, but similar arrangements will have useful civilian applications.

In summary we may identify the scientific users of ROVs and manned submersibles as developers, deep-ocean, and coastal/continental shelf science interests. The tasks that they need to have performed have not to date been carried out on any significant level by ROVs, and have been carried out by increasingly sophisticated (although simple and reliable) surface means, or by limited means of manned submersibles. The effectiveness of the various means are not readily comparable and non-economic considerations are very strongly in favor of use of the manned system when possible.

It was noted by one member of the oceanographic community that current financial pressures have threatened surface vessels capabilities of most scientific institutions. Thus they have no plans, let alone means, for aquiring any tethered free swimming ROV for scientific use. There have been some proposals for the in-situ evaluation of ROVs alongside manned submersibles. This was to have taken place during 1979 (sponsored by the Office of Ocean Engineering of NOAA, as part of their ROV evaluation work). This project has not yet been reported.[18] It appears to be important information to have available.

2.2.5 Military Applications for Underwater Systems

Due to the variety of activities of the Navy, this section is only concerned with the applications for undersea vehicles. The US Navy has in general a mandate to attempt to maintain absolute control over the ocean environment, for both tactical and strategic system requirements. The way by which this is translated into practical actions and systems includes includes both basic and applied science and technology. Although the various laboratories of the Navy do not in general have a task oriented program for undersea vehicle/teleoperator utilization, the Navy is probably the largest sub-system development source for the technologies which make UTs, manned submersibles, and ROVs commercially available.

Under the general justifications of support to security functions the Navy has carried out extensive vehicle related studies and development. With the general imperatives for retrieval capability at virtually all depths of the oceans, the Navy has developed an extensive stable of different classes of un-manned and manned vehicles.

The military applications of ROVs have been summarized by Busby as follows:[19]

<u>Inspection</u> (Aircraft crach assessment/sunken craft assessment/ hardware inspection)
<u>Survey</u> (accoustic and video/photo including geological)
<u>Search-Identification-Location</u> (primarily classified/ordnance)
<u>Retrieval</u> (explosive ordnance/hardware/vessel and vehicle recovery)

Although these categories comprise a large fraction of the Navy work with undersea vehicles, they do not explicitly state the types of activities which these tasks support. This would include emplacement and maintenance of undersea listening devices, other aspects of Anti-Submarine Warfare (ASW), and the many types of research, both basic and applied, that are required to support in general the Navy's underwater activities.

Although it is not widely documented or discussed, there seems to be a large amount of work carried out by the Navy in support of the installation and maintenance of seafloor cable systems. These systems are employed by the Navy in increasing numbers. Applications include power and communication transmissions to and from remote locations, accoustic research and development ranges, and surveillance system trunk lines.[20]

The Navy's activities underwater are divided into three areas based on the means utilized, and the research and development organization follows approximately the same divisions (for non-ONR work);

1) Manned Submersible Vehicles
2) Un-manned search and recovery
3) Diver/Swimmer equipment

The Navy's developments in undersea technology are closely related to non-combatant deep submergence systems and capabilities and this implies support of strategic systems, and some activities in support of operations originating on the surface, i.e., with vessel or aircraft retrieval.

An important factor in the development of the Navy's underwater capabilities seems to be the ability to recover an object in a minimal amount of time. This requires the ability to locate and assess objects. This has been important during the recovery of an H-bomb off the Spanish coast (1966) and also in the attempts to locate and assess the conditions of the stricken submarines the THRESHER (1963) and the Scorpion(1968). These incidents have provided impetus for continued system development, much of which is orientated toward ROV capability.

A major area of work to supplement the tracking and search activities, has been the Navy's broad ranging and highly productive accoustic device and systems development. Although ranging from material properties developments and study, to information precessing analytics and devices, this area has had a profound impact on the capabilities of both naval and civilian underwater systems. Only in the past few years have sophisticated accoustically based positioning devices/navigation aids been available, allowing for precision for all offshore vehicle users.

The general field of accoustics continues to be an area from which all the various underwater vehicles will gain in capabilities. The drive behind this development will continue to be Navy projects which have some "trickle-down" to the civilian sector. The Navy is continuing to develop large scale and costly systems for ASW. Some of the major systems reported are as follows; (1) Fixed detection systems, the best known of which is the long range SOSUS/Caesar bottom mounted hydrophones; (2) SURTASS, the Surveillance Towed Arrays Subsystem, for long distance accoustic propagation, utilizing relatively low frequencies and very long hydrophone arrays, now in the form of towed arrays; (3) Deployable Fixed System, an updated utilization of Sonobuoys; (4) Tactical Towed Arrays, for listening to submarines; (5) various updated types of submarine sonar systems, for various classes of submarines.[21] These systems indicate the type of mission hardware or activities which the Navy vehicles may be used in conjunction with (i.e. support, installation, etc.).

An important point with the Navy work in developing systems or subsystems, is that much of it is carried out (when publicly disclosed) as independent exploratory development of the various laboratories. In this way end users are not identified. Whether done to avoid end-use disclosure or not, the result is that a large amount of the Navy's work in the underwater area, which have vehicle/system applications, is basic research, both in operational and laboratory settings. Much of this development would be applicable to the civilian sector.

Information on the methods by which the Navy carries out its underwater tasks was not obtained, and task analysis for the Navy's non-developmental activities have not been obtained for this report. The Navy does carry out a significant amount of surface diving and operation of both manned submersibles and ROVs. The approximate amounts of this work are given in the data presented in Section 4.3.3.

2.2.6 Industrial Applications/Users

Although the industrial users of underwater vehicles and systems are by far the largest, there is little documentation on the amounts of activities or the activities themselves. Industrial users require extensive utilization of all of the three major modes of access to depth; divers, manned submersibles, and ROVs. The following groups constitute the major categories of users:

- Commercial system manufacturers/developers
- Ocean engineering/coastal construction
- Offshore oil and gas industry (including pipelines)
- Communications and electrical transmission systems
- Ocean mining ventures
- Government regulatory agencies

The major industrial user (and major user of all sectors) is the offshore oil and gas industry (OOGI). This is the industry which has consistently had operational/mission requirements in excess of what the state-of-the-art has offered for underwater access modes. The break in the late 1960's pattern of moth-balling of the world-wide submersible fleet did not occur until the OOGI required manned submersibles for a variety of functions, primarily in support of major North Sea developments. The Navy/Science community initiated work in the area of mixed gas and saturation diving, but these techniques were not widely exploited until the early seventies, with the arrival of drilling and production depths that the OOGI had reached.

The role of the lesser users, primarily the undersea cable interests is examined next.

2.2.6.1 Submarine Power and Communications-Vehicle Applications

Submarine power and communications cables have been successfully installed and operated for nearly a century. During most of this period the means for installation and access for retrieval for repairs and splicing, have been by surface vessel techniques. This has included the use of grabs, hooks, and other un-impressive but effective devices.[22] The cables have primarily been laid and left exposed on the sea-bed. This reflects the depth at which fishing was limited, a depth which is now on the increase. In some cases additional ballasting or cover was provided for cables, to provide for stability in high current areas, or for minimal protection in fairways.

During the sixties a cable burying plow was introduced, capable of burial of cable during cable laying. This originally met the civilian/industrial user requirements. It does have inefficiencies, primarily that the plowing/burial technique is suitable for an approximately one knot operation, while cable laying vessels may operate at speeds up to eight knots when laying only. Also the plow requires a bollard pull on the order of 50 tons, which is a particular support vessel specification. The Sea Plows (I thru IV) are limited to operations in depths of maximum

3,000 feet. (These characteristics do not satisfy the Navy's speed and depth criteria).[23] This equipment has partially fullfilled the industry requirements for burial/installation purposes, but retrieval has been a time consuming effort.

In the past few years there has been some utilization of manned submersibles and ROVs by cable installers and operators. This has been for route selection, installation assistance, and post installation inspections. This has included both free-swimming and towed ROVs. Although this is not a large area of application of ROVs, it nonetheless has significance due to the depths involved, and the fact that the Navy has its large surveillance systems, for which a variety of systems are being developed.[24] The reports on this work do not in general specify the end use of the equipment.

In addition to the Navy work in this area, there has been a family of sophisticated ROVs produced by AMATEK-Straza Division. These are the SCARAB vehicles (Submersible Craft Assisting Repair and Burial). These have been designed in response to the needs of the marine/telephone industry, and to the specifications of Transpacific, Inc. (a subsidiary of A.T.&T.) and a consortium of cable companies. This system is designed to provide surveillance, repair, and burial of submerged telephone cables and operates to a depth of 6,000 feet (1829 m) to locate, unbury, attatch, cut, recover, and bury a cable in a minimum amount of time. The use of ROVs for this support function is not yet established and the two SCARAB vehicles were still completing sea trials in 1979. Notably, the manufacturer of this vehicle is a major contractor to the US Navy and has provided at least sub-systems for some of the Navy's most sophisticated ROVs, illustrating the type of development flows that are typical for many ROV manufacturers.

Other systems like bottom crawling ROVs are used in support of cable installation and maintenance. Pipeline and electrical cable installations in the shallow coastal areas have been traditionally serviced by surface divers, and as such have not been a significant factor in the utilization of manned submersibles or ROVs.

2.2.6.2 Other Industry Users

The use of ROV support for deep ocean mining activities is presently not a significant factor. Use of towed accoustic arrays, cameras, etc., has been reported, and towed ROVs have been purpose build for such ventures. A discussion of the mining community's needs and utilization of ROVs is not presented here but rather in section 7.3 along with other future uses for vehicles.

General ocean engineering and coastal users of ROVs are limited and not documented, however this includes use of vehicles for survey of sewer or pipe outfalls. The use of SCUBA or mixed-gas non-saturation diving is most common for shallow water work, e.g. for piling or structure examinations. The safety implications of use of surface diving/bounce diving techniques are not well documented. There is some data available, which seems to indicate that along with amateur diving these shallow water users of diving systems present a larger safety problem than almost all of the OOGI and other deep-water system users. This is discussed further in section 5.3.2. It is really a serious safety consideration, since the economics of shallow water activities do not allow any use of expensive remotely operated systems, when simple mixed gas systems, or SCUBA are cheap and readily available.

2.2.6.3 Offshore Oil and Gas Industry Use of Underwater Systems

Because of the dominance of the offshore industry over the development and utilization of underwater vehicles, divers, and hybrids, this is the subject of the next section. Most of the considerations of this report are directed toward the current and future applications of undersea teleoperators in the context of the offshore oil and gas industry, since they seem to carry most of the current costs of systems and the depth regions of this industry define the state-of-the-art. The major developments in ROVs have been to provide the OOGI with usable tools for everyday operations as opposed to Navy development, or irregular scientific usage. The dependency of the industry on increasingly sophisticated means for access to increasing depths is apparent in the literature, and will undoubtably provide the direction if not the support for the next generations of systems.

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SECTION 3. OFFSHORE OIL AND GAS INDUSTRY UNDERWATER ACTIVITY

3.1 General

The operational aspects of offshore activities using ROVs and other underwater access modes is presented in this section on an activity-by-activity basis. Some of the offshore tasks are within the capabilities of ROVs. Other such tasks are performed by divers or manned submersibles, and will not easily be accomplished by use of ROVs because of economic considerations, often the secondary economic effects of doing the tasks in a slower or more difficult way.

This section attempts to clarify the types of offshore activities and the background of why the activities take place in the manner that they do. With this information, utilization rates and cost/safety considerations may be made with a better understanding of overall operational goals.

Teleoperator systems are not specifically discussed here. The detailed descriptions of activities are necessary to give an appreciation of what general situations the various underwater tasks are in support of. Eventually many of these tasks will be performed by ROVs.

3.2 Offshore Oil and Gas Operations

A logical way to describe underwater activities is to follow the chronological sequence of the development of an offshore oil or gas reservoir. This development follows a time and sequence such as is shown in Figure 3.1. Although this figure generally applies to the smaller US Gulf of Mexico projects, the major foreign (North Sea, etc.) projects differ only on minor points, mostly to do with development decisions,

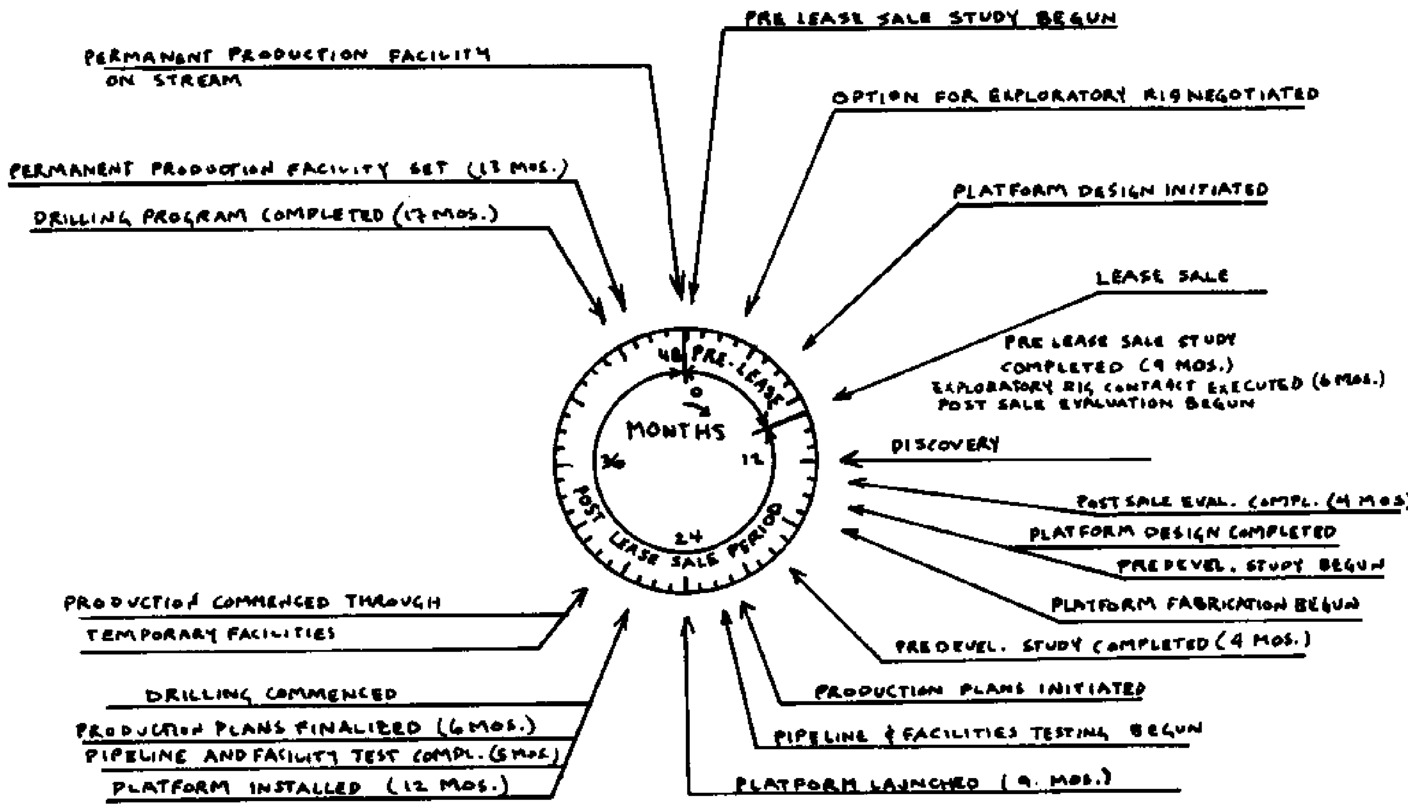


FIGURE 3.1 HYPOTHETICAL FIELD DEVELOPMENT PROGRAM.

Source: Don E. Kash, et.al., Energy under the Oceans: A Technology Assessment of OCS Oil and Gas Operations (Norman OK, 1973) p 49.

rather than operational durations. For most parts of the world, including the US Gulf, there are distinct construction seasons, which allow for reasonable weather, or at least periodic "weather windows". These are necessary for carrying out the more critical operations such as structure float-outs, jacket setting, or other installation efforts that require up to a five to six day calm period. Operations like these require reliable and expedient means for carrying out all aspects of the operation, and are often such than once started they must be completed. This requires detailed planning and knowledge of support system capabilities. This in turn produces a conservative approach to choice of method. Methods or equipment that work will be used again. Methods that have any difficulties are usually not pursued if less difficult means (even more expensive) are available. This applies most often to support equipment such as diving means or other underwater systems, which have known capabilities and will be reliable when called upon.

Other aspects of the offshore operations are not as exacting in terms of overall needs for large amounts of equipment working at one time. These are more amenable to utilization of ROVs or newer systems, because the activity may be carried out in a more flexible time space (such as long term inspection programs), and less than satisfactory performance (during initial utilization) will not have as many down-stream effects.

The following breakdown of the steps involved in development of offshore fields is used to identify the underwater activities:

Exploration Activities
- pre-drilling surveys
- exploratory drilling

Development
- pre-construction surveys
- platform installation/construction support
  - inshore preparatory works
  - tow-out and immediate works
  - offshore piling and initial work
  - construction support
- pipeline installation/construction support
  - pipelaying

Development (cont'd)

tie-ins

post installation survey

sub-sea completions

installation/operation

Production

Inspection and monitoring/maintenance

steel piled jackets

concrete structures

pipelines

risers

repairs/maintenance

The first step in the overall development is the period of exploration activities - comprised of regional surveys, detailed surveys, and exploratory drilling.

The initial reconnaissance activities are passive and are carried out by surface ship or air-borne equipment. Although the Arctic areas may require some under-ice vehicle capabilities this area of ROV application has not yet been reported on, except for limited apparent equipment development activities, by the Navy.[1] Satellite usage is feasible but the extent of use is not known.

The second phase of exploratory work is the detailed survey period. This includes sea-floor mapping, deep and shallow seismic surveying, magnetic anolomy survey, bottom sampling, and coring. These tasks are primarily carried out from surface ships, but some sources have described the use of manned submersibles and ROVs to obtain core samples from areas with slopes which prevented the use of conventional surface techniques.[2] The use of vehicles for this application may or may not have been in support of oil and gas exploratory work, but nonetheless may be possible. Seismic surveys have been carried out primarily from surface vessels, but micro-seismic methods may soon increase the potential for application of ROVs in support of this activity. Pre-drilling activities such as bottom coring require government permission from various levels and only occur well into the exploration program, or are done for the governments information in helping to determine suitable tracts for future lease sales.[3]

The final phase of exploration consists of exploratory drilling. The use of temporary mobile drilling vessels of various types is the rule, and is similar in all areas. The exceptions to the exploratory drilling in the normal manner are the infrequent but possible use of wildcat wells as initial immediate production wells. This has occured in Brazil in order to produce immediate income, and although it is exceptional, it may become more commonplace. This will present new demands on the standardization of exploration drilling underwater equipment (such as the semi-submersible production set-up used in Spain) which have a short lead time and rely more on subsea techniques, rather than construction of large permanent production facilities. In most situations the exploratory well is shut-in after the reservoir evaluations are made.

After assessment of the reservoir's economic feasibilities, the next step in the field development is the planning of the permanent or semi-permanent production facilities. This usually requires a detailed survey of the seabed for information of soil, bearing capacities, etc., to be used for platform design inputs. This will entail additional coring activities, pipeline route and feasibility surveys, environmental baseline surveys, and any remaining mapping detailing etc. This phase may utilize manned submersibles and ROVs to a large degree.

When plans are finalized and onshore fabrication is carried out the offshore construction commences. This is seasonal work, and the offshore activities are dependent on reasonable weather criteria. Although there are some activities carried out on a year-around (discontinuous) basis, even in the North Sea, the most demanding developed area, the majority of installations are planned to take place during the summer season. This generally restricts diving or underwater activities to about eight or nine months of the year, for most locations.

The construction of the jackets (for steel structures) and submerged concrete platforms is carried out in onshore or inland locations. The major structures are towed out (either self-floating or on large pontoons/barges) and installed in the field during the early to mid-summer. This marks the beginning of the period of intense offshore activity, both above and below water, in order to complete the structure as soon as possible and to begin development drilling. For self-floating concrete and steel structures the need for underwater activities will begin in the inshore stages with the preparations for tow-out or deck mating.

In addition to the main platform, a field will generally require a gathering pipeline or tanker loading system, and possibly a separate flare structure. This applies in general to the major North Sea fields and to a degree in the US Gulf of Mexico and West Coast developments. The installation of pipelines and tanker loading facilities are carried out at approximately the same period as the platform (or platforms on major fields) and because of this they may become critical path activities which are competing with the general construction for access or equipment. This causes large penalties for breakdowns since if one process is stopped unnecessarily, major amounts of equipment are tied up.

The installation of structures and the associated work below waterline such as tie-ins are followed by post installation inspections such as pipeline pressure testing or clean-up of the sea bottom in the area. These activities (underwater) are not necessarily on the critical path and have less priority. Because the directional drilling techniques employed today are limited to reaching areas of the reservoir out to a radius of approximately 3 kilometers, the main platform may be augmented by use of satellite wells, utilizing subsea completions and small diameter intrafield flowlines, which provide additional underwater work during the same period as the central platform. This may add to congestion in the field and will possibly affect access.

Generally there are post installation underwater inspections of the structure which are carried out as part of the installation process. During the life of the structure there are further certification underwater inspection and maintenance requirements for the structures. Although minimal, there may be some need for underwater repairs.

Due to the variety of weather and depth ranges in which Outer Continental Shelf (OCS) development is carried out, the rest of this report is primarily concerned with the more difficult areas in which offshore operation are carried out. This would include the deeper portions of the Gulf of Mexico, deeper areas off the West Coast of the US, potential Mid to North Atlantic US areas, North Sea northern areas, SE Asia and Australian deep water areas, and other frontier areas with little present activity but high potential, such as off Newfoundland, etc. The reason these areas are of concern is that there is an increasing move to more hostile environments in the development of OCS oil and gas. The methods developed for shallow water areas are not of present interest because they will be established techniques. Unfortunately most of the operational information available has been reported about the recent North Sea activities. Because of the lack of available information much of the discussion is based on problems and techniques used in North Sea development, to which the generalizations may have to be limited. Since the North Sea operations represent some of the most difficult situations,the cost and safety concerns may be fairly valid in general - except that North Sea operators would be willing to bear greater costs to overcome greater human risks.

3.2.1 Underwater Activities in Support of Exploratory Drilling

The support of exploratory drilling requires the following underwater tasks. They may be carried out by use of divers, manned submersibles, ADSs, and ROVs. The following categorizations have been suggested:

1) Re-entry of drillstring, casing guide base, and stack
2) Inspection of guide base and BOP stack
3) Riser inspections
4) Miscellaneous work, i.e. bottom surveys, beacon work, equipment retrieval.

The second and third categories are carried out on a regular basis in addition to the event triggered needs. The actual tasks that make up this work include the following:

- assist installation of temporary guide base, permanent guide base, surface casing, drilling BOP stack, drilling riser, hydraulic control pod, removals
- change out of guidelines; hydraulic, choke, kill lines
- operate emergency hydraulic supply for BOP disconnect
- operate mechanical overrides on collet connectors
- replacement and final check of AX/BX rings
- repair and reconnection of wellhead riser automatic fillup valve hoses
- replace riser angle indicators on riser pipes
- preperations for abandoned well-head re-entry, (check template alignment, guideposts, install guidelines)
- assist in abandonment of well head, (cutting off casing, debris clearance, etc.), demolitions
- retrieval of lost equipment; drill bits, casing slips, BOPs, riser joints
- replace pingers and transponders on BOP and guide frame
- replace bottom mounted pinger/transponders of vessel navigation/ positioning system
- well head marking
- general growth cleaning of wellhead equipment
- inspections of riser, well-head, guidelines, hoses, base and riser inclinations
- bottom reconnaissance

- geological observations
- inspection/video of chains, anchors, anodes of drilling vessel
- inspection of jack-up vessel legs and mats, scour

The actual drilling support activities for an area will depend on the water depth which determines the type of rigs used. Also,the vessel requirement depends on the area's weather conditions, currents, and bottom/geological conditions.

The types of drilling vessel in use and their hull types/mooring system types are shown in Figure 3.2.

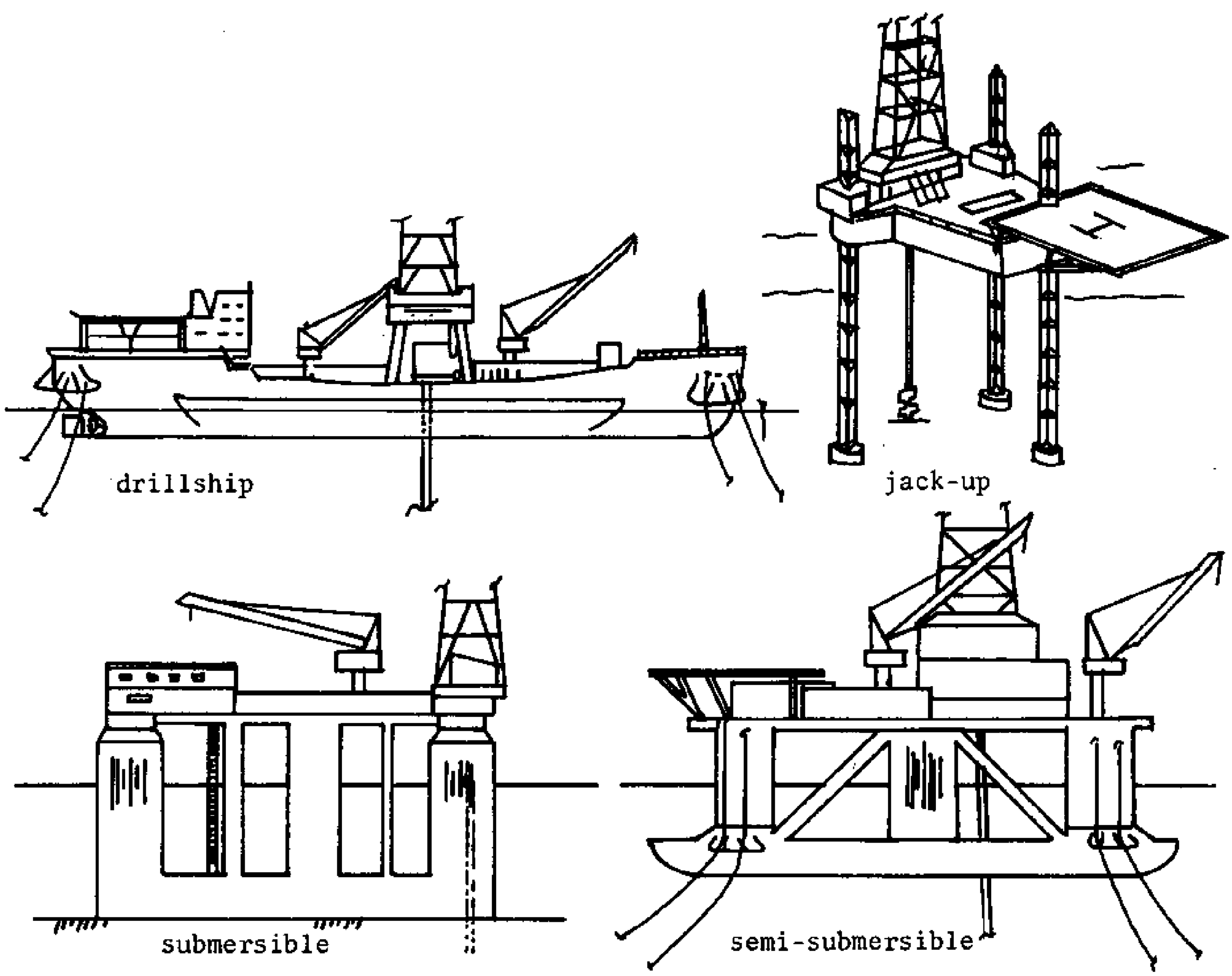
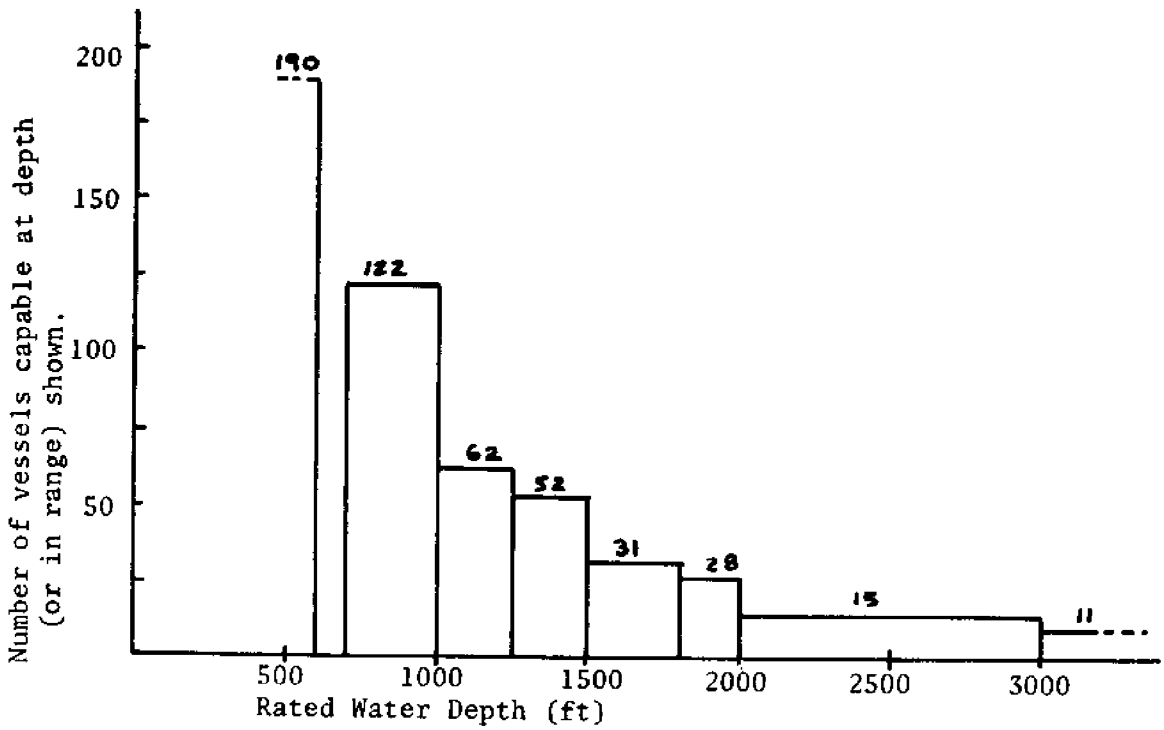


FIGURE 3.2 TYPES OF DRILLING VESSELS.



Source: C.K. Orr, "Drilling Contractor's Role in Deepwater Operations," Proc.AIME Deep Drilling and Production Seminar, 1979, SPE 7845, p 62.

FIGURE 3.3 DRILLING VESSELS - DEPTH CAPABILITIES

Figure 3.3 indicates the water depth capability distributions for drilling vessels (this includes the world fleet), and gives some indications of the types of depths to which drilling support underwater activities are becoming aimed at. The actual drilling depths are short of the vessel capabilities. Exploration drilling in water depths up to 2,000 feet is becoming conventional, but the field development of these depths is lagging far behind. Table 3.1 gives the number of wells drilled per year for recent years, in water depths over 1,000 feet.

All drilling from floating rigs requires the use of BOPs on the bottom, while the use of jack-ups may or may not require them, depending on the local conditions. Submersible type vessels are ballasted to rest on the bottom and are used in depths between 10 and 100 feet. Jack-up rigs are used in depths to 350 feet, while drillships and semi-submersible designs are used to the most extreme depths.

TABLE 3.1

DEEPWATER WELLS DRILLED 1975-1979

	600 - 1,000 feet	Over 1,000 feet	Total
1975	21	16	37
1976	38	31	69
1977	26	28	54
1978	21	24	45
1979 (est.)			40 to 50

Source: C.K. Orr, "Drilling Contractors Role in Deepwater Operations". Proceeding SPE-AIME Deep Drilling and Production Symposium (Amarillo TX April 1979) S.P.E. 7845

The over-riding characteristic of the underwater work in support of drilling operations is that its needs are intermittant and unpredictable. A dive summary of a rig utilizing an ADS for drilling support is given in Table 3.2 (Drilling Rig ADS Dive Summary).This shows the typical short duration of the tasks on an irregular basis, with some regular inspection needs. Another source notes that the average number of dives which may be expected per location is 15 to 20 over the average 3 month period for completion of a drilling program.[4] Although the cost effectiveness of the support methods is the subject of another section it may be noted that rig support has been carried out on diver-only,ADS-only, or manned submersible-only basis. There were no reports to date of the use of an ROV by itself to carry out all of the needed tasks. Reports include the use of ROVs to carry out part of the total work load, but whether or not

TABLE 3.2

DRILLING RIG ADS DIVE SUMMARY

DATE	DURATION	OPERATION
July 16	1 hr 25 min	Practice stabbing guide wires using Cameron Guide Wire Spear. Operator training.
July 16	37 min	As above. Operator training
Aug. 23	65 min	Observation to base plate check No. 2 TV wire damage. Wire tail still in socket.
Aug. 23	2 hr 15 min	Cut No. 2 guide wire from base prior to re-establishing TV guide wire using hyraulic cutter.
Aug. 24	5 hr 30 min	Stab No. 2 guide wire using Cameron Guide Wire Spear. Wire established.
Aug. 29	42 min	Observation check leaks on blue and yellow pods. Vibrations felt on ADS walkway on BOP.
Aug. 30	1 hr 19 min	Observation to check position of broken No. 2 guide wire.
Aug. 30	3 hr 05 min	Cut No.4 guide wire prior to stabbing new guide wire
Sept. 3	4 hr 08 min	Stabbed No. 4 guide wire unable to cut wire from guide frame.
Sept. 4	2 hr 51 min	Cut No. 4 guide wire from guide frame. No. 4 guide wire established.
Sept.20	1 hr 03 min	Observation to top of BOP. Observed pods. Ball Joint Guide Wires. Check for vibration on BOP.
Sept. 26	1 hr 17 min	Observation of above.
Oct. 3	2 hr 12 min	Routine observation (weekly) as above.
Oct. 15	1 hr 30 min	Untangle hydraulic hose for fill-up valve line broken.
Oct. 15	2 hr 42 min	Remove broken hydraulic line from riser fill-up joint.
Oct. 15	35 min	Replace broken hydraulic line to riser fill-up joint.

Source: T.C. Earls, D.S. Fridge, and J.F. Belch, "Operational Experience with Atmospheric Diving Suits," Proc. 11th Annual Offshore Technology Conf. 1979 p 1533.

other means were also available on the vessel at the same time is not clear. Some reports suggest that the operator will be equipped with an (un-manned) saturation diving system, and when divers are needed they may be mobilized from shore. Options and costs vary from situation to situation, depending on the depth and the location. However the use of manual (diver) intervention is being avoided at depths greater than 200 m, although potentially it may be used to approximately 500 m.[5]

The use of an ADS (JIM/Anthropomorphic type) may be limited to bottom tasks. It requires adequate planning and installation of access staging on the temporary guide base, permanent guide base, and BOP stack itself, along with a mobile stage (elevator) when possible. Thus the use of a limited capability system is possible when advance planning and fabrication/modification of equipment is possible.

Some field development has included the use of subsea or bottom drilling templates. These allow for the drilling of development wells (used for production as opposed to evaluation or wildcats) prior to the installation of the above water facilities. The drilling is carried out through the template which acts as a multiple guide base and manifold structure. By the time the permanent production structure is brought to the field the development drilling is well along its way and the time to get the field on stream is reduced. The drilling through these templates is similar to exploratory drilling, although the underwater work includes installation of the template or base. Template installations are often performed using the drilling vessel and drill string techniques. This includes use of accoustic positioning systems and some intervention capability. However recently available systems allow for accoustic tilt data telemetry for information on the attitude of the installation and help limit the use of other intervention to a minimum.[6]

The underwater support of drilling operations is a primary target for development of teleoperator oriented systems, and a few systems are on the market that allow for almost interventionless operations. These are reported on for use in deep water situations, and the economics of the sub-systems are not known. They do not yet appear to compete with divers or submersibles for relatively shallow water operations (i.e. less than 200 meters), which are the short dive/minimum system situations that may present the most difficult implementation of substitution of teleoperators for safety justifications.

3.2.2 Platform Installation/Construction Support

The general activities concerned with the installation of offshore production structures (incorporating drilling, production equipment, and accomodations) differ between those associated with steel piled jackets and concrete gravity structures. Most of these differences have to do with the stage of completion of the deck facilities and are of no consequence to underwater activities. However for the steel jacket piling type structures the piling activities make up a large fraction of the underwater related activities.

The North Sea platforms installed north of the 56 parallel have exceeded the previous dimensional and logistics requirements and included the introduction of concrete gravity structures. The massive concrete constructions are self-floating structures that allow most of the above water (deck) hookup to be completed prior to tow-out. The general technique is shown in Figure 3.4. The introduction of large (in area of plan) steel jackets also surpassed the types used in the Gulf of Mexico in the

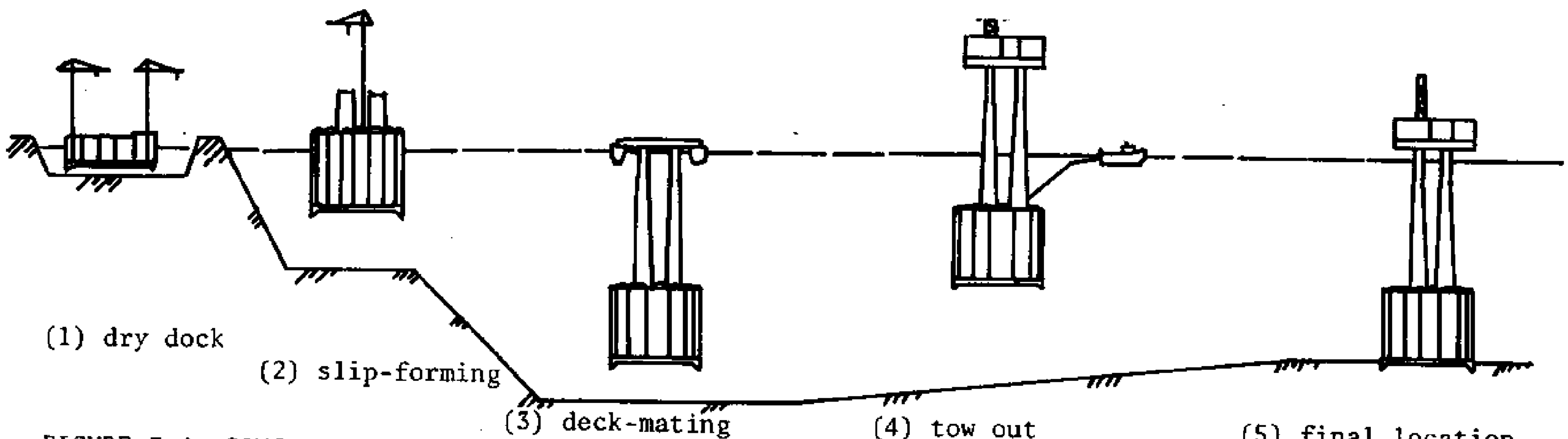


FIGURE 3.4 CONCRETE GRAVITY STRUCTURE CONSTRUCTION SEQUENCE.

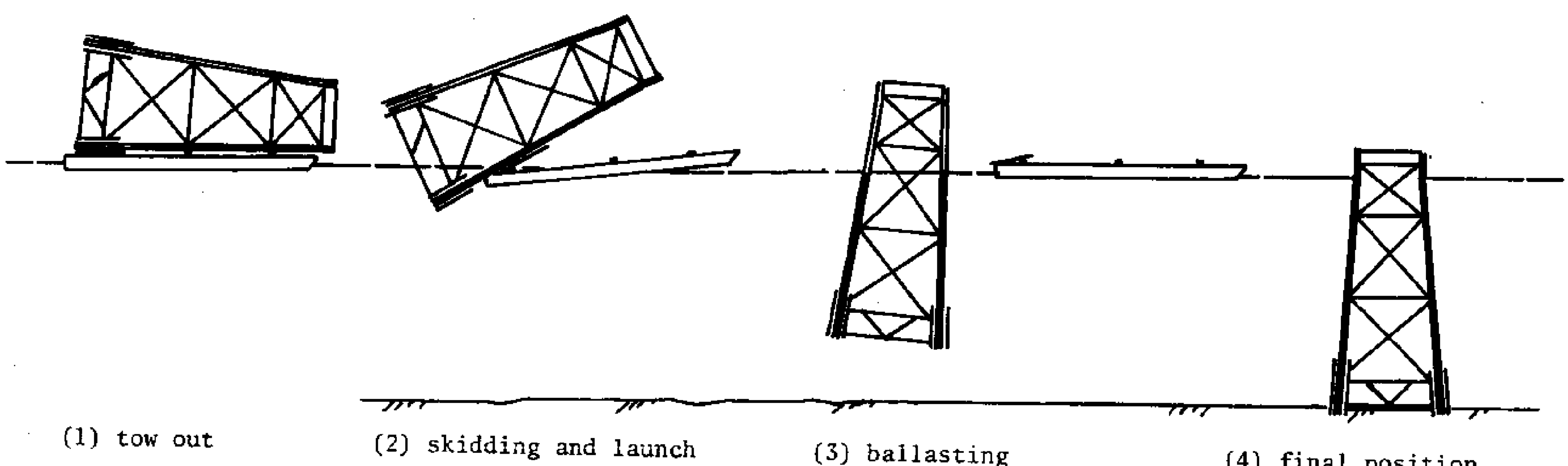


FIGURE 3.5 STEEL JACKET INSTALLATION SEQUENCE (BARGE LAUNCHED)

early 1970s, and are basically different in terms of total deck loads and environmental loads. This has led to structures with very large underwater portions and very large diameter tubular members, and somewhat complicated node designs.

Appendix D gives data on the major North Sea fields along with the water depths and structure types indicated. Recently installed structures in the US Gulf of Mexico have exceeded the depths of North Sea fields and include structures in depths of up to 1,025 feet (maximum) with a few structures in the 600 to 700 foot depths.[7] However, most structures in the Gulf are in less than 300 feet of water and are designed for less severe conditions than North Sea structures, hence have smaller members, nodes, and much more straight-forward construction and operation logistics.

Use of underwater intervention may begin with the inshore activities, primarily for concrete structures which are constructed initially in drydocks and then floated and slip-formed. This requires temporary mooring, and deck mating procedures will require submerging the floating structure as deep as 150 meters, and will include some underwater inspection and rigging of moorings. Prior to tow-out concrete structures require detailed surveys of the structural and mechanical components below the water line, including the externally accessable components of the ballast system and structural skirts. Procedures may include use of underwater intervention (by divers or sub, ROV, etc.) for ballast system back-up,etc.

Steel jackets are normally barge launched at the offshore site (shown in Figure 3.5). This will require support barge/vessel facilities and some temporary mooring, which is usually surveyed prior to a jacket launch (for major structures).

After deballasting the steel or concrete structure into its final position on the bottom, intervention is made in order to check the immediate conditions of the bottom, the skirt penetrations, and the hydraulic and ballast valving. Then survey or minimum operations are carried out.

After the initial location of the steel jacket the piling is installed, commencing immediately for a minimum securing capability. This requires dropping pre-installed (in the guide) piles or stabbing, and lowering piles into jackets that have no pre-installed piles. Pile driving will include use of pile followers or extensions, sometimes requiring use of divers for fitting releases. Underwater hammers are now in use and have great applications for deeper jackets. Pile stabbing, followers, and pile driving require divers or other observation means. Limited underwater rigging is required, but is nonetheless a necessity especially when difficulties arise with chasers or hammers. When the pile driving is finished the piles are grouted into the sleeves and this requires use of (sometimes pre-installed) packers which seal the annulus to contain the grout. Usually this procedure requires a detailed inspection of the packer/seating, and visual confirmation of the presence of grout at the proper locations (vent or tell-tale). The un-needed ends of the piles are generally removed, requiring very diver intensive oxy-arc cutting and rigging for removal.

Other platform installation related activities apply to both concrete and steel structures. This will include site inspections, settlement surveys, debris clearance, cathodic protection monitoring, removal of installation aids (such as grouting equipment, hydraulic equipment, towing and mooring lines, sometimes ballast tanks, or other structural items), and other miscellaneous activities. This may require the use of underwater burning gear and possibly shaped charge explosives, both techniques primarily but not solely within the capability of divers, although recent reports of use of ROV and manned subs include placement of charges. These construction support activities are all rigorous, difficult, and generally diver intensive. They include a high potential for unanticipated or difficult to eliminate problems such as damaged or stuck valves, installation induced minor damages requiring minor repairs such as replacement of grout lines or fittings, or anodes, and generally difficult to predict problems for which the diver's dexterity is usually needed. For this reason all platform installations have some diver capability and may include the use of a manned submersible in a minor capacity, say for reconnaissance, inspection, or diver support.

Also the installation of concrete structures may include the installation of anti-scour measures, such as matting or aggregate. This will require surface vessels with underwater intervention for positioning and control purposes.

The underwater support for these types of construction activities is very much the lucrative work of diving companies. Typically this will require a major system with up to 12 men in storage at depths. The total support crew will be on the order of 20 to 25 persons for a total of approx. 35 men. Data from the diving operations conducted in support of the CONGNAC platform installation indicate the vast amount of diver support utilized for a major strucutre. Although this platform entailed much more than the usual amount of underwater work (having been installed in three vertical stages) it indicates the amount of work than remains outside of present ROV capability, since ROVs were employed as much as possible on this job.

TABLE 3.3

COGNAC INSTALLATION DIVING STATISTICS

SEASON	1977	1978
Days in saturation	122	79
Number of bell runs	56	41
Total excursion time in water	338 hours	295 hours
Total sat. man-hours (at storage depth)	14,000 m-h @ 910 feet	n.a.

Source: A.O.P Casbarian and G.R. Condiff, "Unique Diving Skills Aid Project" OFFSHORE August 1979 p 51.

In addition to this saturation work there were hundreds of hours of surface diving logged.

Despite the current work being carried out on remote sensing methods (such as grout sensors, accoustic guiding devices, etc.) there will continue to be a major requirement for divers for large platform installations. Major diving companies are confident that this work will remain exclusive to divers and provide a large source of employment for their services, regardless of submersible and ROV capabilities.

3.2.3 Pipeline Installation and Construction Support

The underwater intervention needs for support of pipelaying operations is very dependent on the actual depth of water in which the pipeline is being laid and the size and type of pipe involved. The traditional method is to make up the pipeline from 80 to 100 foot long joints which are welded into a string at stations on a pipelay barge, while the pipe is lowered to the seabed. The general technique is shown in Figure 3.6. Barges are dynamically positioned or more generally moored with 8 to 12 anchors set at a distance of up to 3,000 feet, and these anchors are continually relocated allowing the barge to move along while maintaining a high tension on the pipeline thus preventing the pipe from buckling. Pipelines are laid in this manner in water depths up to 1,500 feet, with the deepest attempts to date being laying of a trans-Mediterranean pipeline in depths of up to 2,000 feet for limited areas.[8] Larger trunk lines in the North Sea are 30 to 36 inches in diameter and are installed in depths of 200 to 600 feet. Conventional lines have a concrete coating for lines in excess of 6 to 8 inches in diameter to provide a negative buoyancy when internally dry, and to provide some protection for the line.

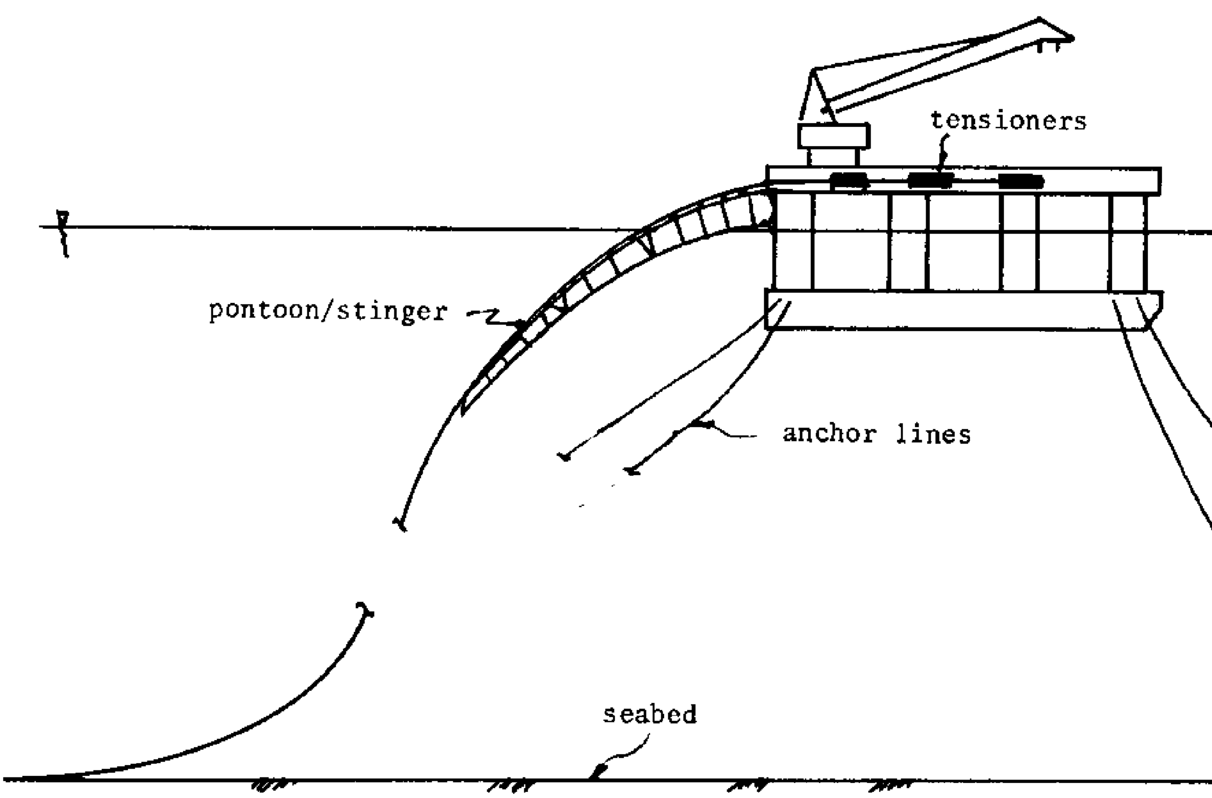


FIGURE 3.6 SEMI-SUBMERSIBLE PIPELAY BARGE - STOVEPIPE METHOD

The pipeline installation operation requires underwater intervention during all of its phases on at least an intermittant basis. This includes:

- pipeline route surveys and sampling (with sidescan sonar echosounder, rock and sediment sampling)
- pipeline route inspections (for debris, anchor dragging evidence, trawl board marks)
- pipeline stinger and seating inspections
- minor repairs and adjustments to stinger ballast and hydraulic systems
- video and visual inspections of pipeline in laid position
- pigging tracer and inspection follower
- pressure testing support (leak detection)
- pre-burial/trenching inspections/object removal
- trench profiling/trenching/burial/backfilling activities
- pipeline corrosion protection system survey/monitoring

A resently developed and employed alternative pipelaying method is called the Coflexip system and is essentially a "flexible" steel/plastic compound pipe used in diameters of up to 255 mm. The pipeline is formed by an extrusion process and is layed in continuous lengths made up onshore and laid from reel vessels. This eliminates the offshore make-up of the line. Due to the present diameter limitations for fabrication, these lines are limited to intrafield use or smaller field connections, but have had useful applications in early production schemes, satellite interconnections, etc., applications which are on the increase. Diving support for laying is similar to that of conventional laying, but burial and trenching may be done by a plow type device that combines the laying process with the trenching and burial. This plowing device was first introduced in 1979 with a successful installation on the Mobil Beryl field. Although competing techniques are now being proposed/developed, most pipelines are layed by the conventional lay-barge method. Other methods do include the following. The bottom tow method requires sections or all of a short line to be welded up on shore and the completed piece is then towed along the bottom out to the previously plowed trench. Near bottom towing includes use of internally dry, partially or fully ballasted sections of pipe which are to be towed-out a short distance off the bottom, and assembled offshore. A similar proposal has been made for surface towing of pipeline sections. These towed methods require intervention for removal of towing gear, ballasting, tracking surveys, etc. They are intended to avoid the cost premium associated with assembly of pipe joints offshore, by minimizing or eliminating the use of surface laybarges, while not using extreme amounts of underwater support.

In addition to regular underwater activities in support of the pipeline installation some problems entail more critical underwater support. These are buckling accidents during or after laying, and loss of the pipeline due to weather conditions requiring the vessel to abandon the pipeline end. Various techniques have been utilized to terminate the laying operation, most often by use of an expandable plug inserted in the end, prior to lowering the free end to the seabed. This is later retrieved possibly using diver assistance, but usually by use of a retrieval line attatched to a buoy. At the ends of the line tie-ins are performed.

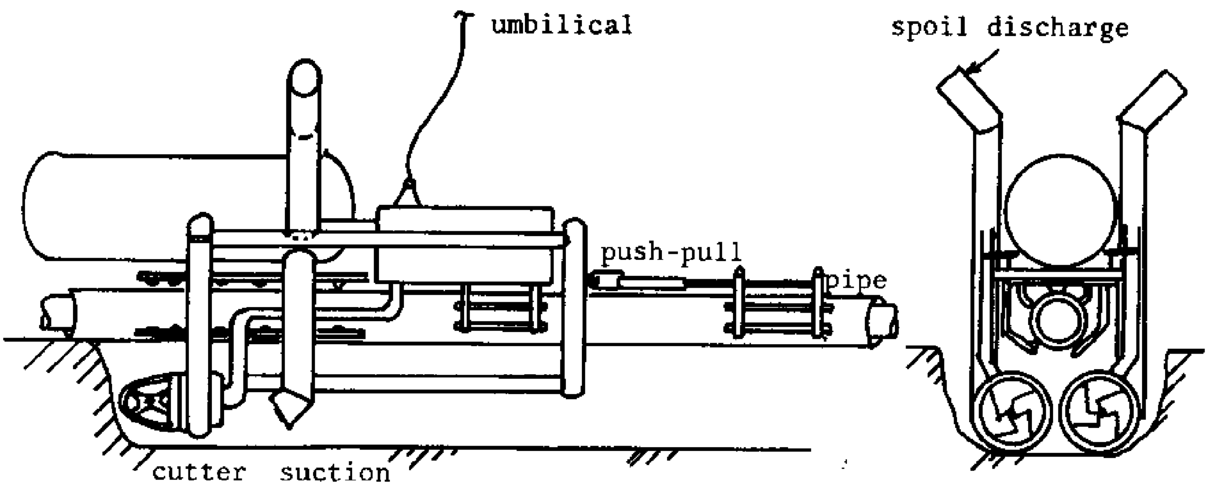
After laying, the pipeline is surveyed for final documentation of spans and positions. Then the pipeline may be trenched and buried.

Normally the regulatory requirements include the need to have the pipeline in a trench. The line would then be normally buried by natural back-filling (due to currents, etc.).

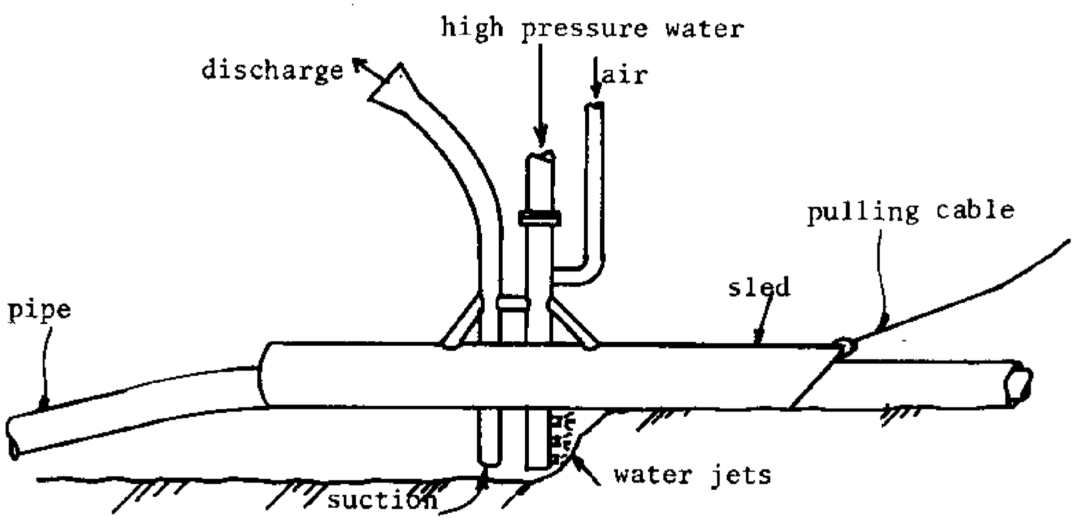
Three methods are available for trenching; machines with rotating cutting heads which can cut through the sediment, "jet sleds" which use water or air-water mixture jets to dig a trench, and plow type devices towed by a surface vessel. The cutter-head type and jet type are lowered onto laid pipelines and as they operate the pipeline settles into the newly dug trench. The plow-type (sometimes with a vibrating plowshare or jetted plowshare) are of two types. One type is used prior to the arrival on site of the towed pipeline, and is used to cut a trench into which the line is then towed/pulled. The other type allows the pipe to be layed simultaneous with the plow burying the pipe at the bottom. Figure 3.7 illustrates the three types of equipment for burial/trenching.

The operation of these devices requires intervention by some means, although to varying degrees, depending on how sophisticated the equipment is. Traditionally the jet barge/jet sled has been used. This requires diver assistance to land the device on the pipeline and for handling the rigging and air/water supply hoses. The diver also relays information on the quality of the trench and redirects the surface crew. Recently ROVs have been able to assist in most of these tasks, however documentation has been lacking. Newer devices such as the Kvaerner-Myrnes trenching device are self-propelled, maneuver to the pipeline, latch onto the line, are surface controlled, and provide performance feedback to the surface, and avoid the use of underwater assistance. However, the employment of this device has not been reported on (beyond developmental testing).

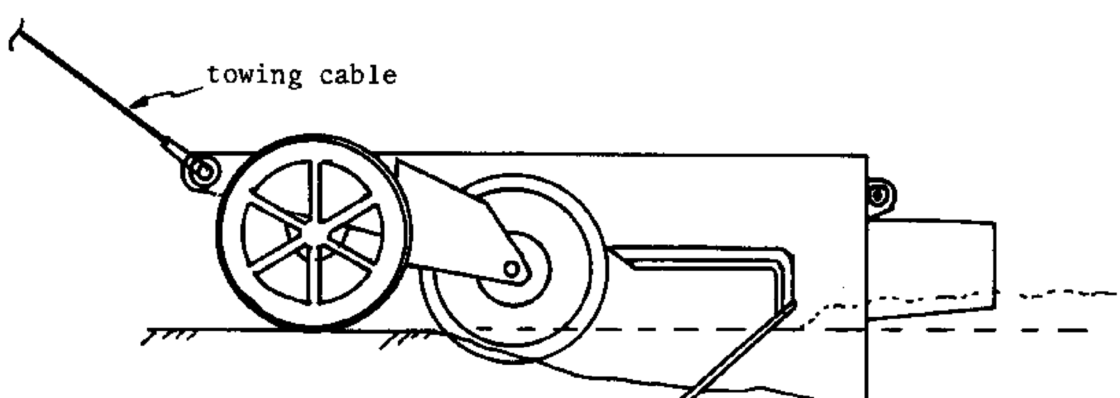
Trenching and burial has been utilized for all but one of the North



(1) Cutterhead



(2) Jetsled



(3) Plow (used prior to pipeline tow out)

FIGURE 3.7 BURIAL/TRENCHING EQUIPMENT

Sea trunk lines. Similar requirements in the US require burial of offshore pipelines. Hoever, there are questions raised regarding its effectiveness in prevention of damage to the pipeline and damage to fishing activities related equipment. Recent studies have shown that an unburied trenched line is likely to cause more damage to trawling gear than an untrenched pipeline. Further studies have shown that trenching is not always effective in preventing damage due to vessels anchors since the trench depth is much less than the depth that a tanker's dragging anchor would reach, thus offering little protection from the anchor, and providing a possible hazard to fishing activities when burial is unsuccessful, (like in high current or sandy areas). A major pipeline (FLAGS) in the North Sea has been layed without trenching in deepwater areas.[9] Impact damage due to trawling gear appears to be minor, and greater damages to lines appears to be due to damages occuring when "jet sleds" are lowered onto the line. The source of these observations also indicated that Norwegian and UK requirements may drop the need to trench deepwater lines for coated and reinforced pipe with a diameter greater than 16 inches if the pipeline is otherwise sufficiently protected.

For some fields and pipelines, the use of concrete saddles and other artificial means of burial/protection are used. This may be due to shifting bottoms, untrenchable bottoms, or locations in seaways, with very high potential for damage. Installation of these types of protections requires divers or submersibles, with many methods reported, including an ROV type device for handling heavy loads, the Kvaerner-Myrnes "SPIDER". The Ekofisk-Emden pipeline required use of crushed-stone fill along great lengths and utilized the "SPIDER" also. Installation of concrete saddles has been reported at more than one location utilizing divers for final locating and set-down procedures.

Pipeline Tie-Ins

Following the laying of conventional pipelines, the line requires underwater hook-up to the terminal structures. In general two methods are used:

1. Tie-in using spool pieces (dog-leg or otherwise)
2. J-tube riser type connections utilizing pipe pulling techniques.

Tie-ins using spool type connections may be welded or may use mechanical connections. Fully welded joints are by far the most reliable (although costly) and are the most widely used for large diameter and deepwater applications.

Due to severe service stress criteria, weld quality requirements for deeperwater pipeline tie-ins and repairs have required the use of dry ambient or dry atmospheric pressure underwater welding techniques. Although wet welding techniques have been utilized for some low stress applications, weld quality from wet techniques have not been acceptable for pipeline requirements due to code requirements. Gas pipelines operate at pressures up to 2,000 p.s.i., and depending on the diameter involved the test pressures may be up to 5,000 p.s.i. The service pressures, along with thermal variations in operation, require pipelines to have high quality construction in order to not require servicing. Manual Metal Arc welds produced in the wet are generally characterized by brittleness (low ductility) and weld defects (such as slag inclusions and unacceptable porosity). These are due to rapid quenching from the surrounding fluid along with hydrogen absorbtion from disassociated water vapor in the arc region. Pre-heat and post-heat treatments are difficult if not impossible. These factors have generally prohibited development of sophisticated welding in the wet (limited use wet systems are available though).

Underwater welding in the dry is accomplished by the use of:

- full size habitats (at ambient pressure) within which the diver takes off his wet suit (for pipelines)
- mini-size habitats (at ambient pressure) within which the diver works in his wet suit (for structural work)
- ambient dry habitats using bell delivery/mating for access
- one atmosphere dry habitats which require bell delivery/mating on the bottom (for pipelines)
- portable dry spot habitat, with either wet or dry hand, where the welding chamber is a small, transparent, open bottomed enclosure over just the locality of the weld and it is filled with an inert gas, while the diver employs the usual diving apparatus.

Typical configurations of these devices are shown in Figure 3.8. The underwater tasks involved in a typical large diameter pipeline tie-in hyperbaric weld are as follows (sketches of these steps are shown in Figure 3.9):

- rough alignment of pipeline to spool/spool to riser/or pipeline to pipeline
- rough cutting of pipe ends by oxy/arc (for removal of excess lengths or damaged sections)
- removal of concrete coating and mastic (by use of hydraulic saw)
- installation of alignment devices such as the Taylor Diving Co.

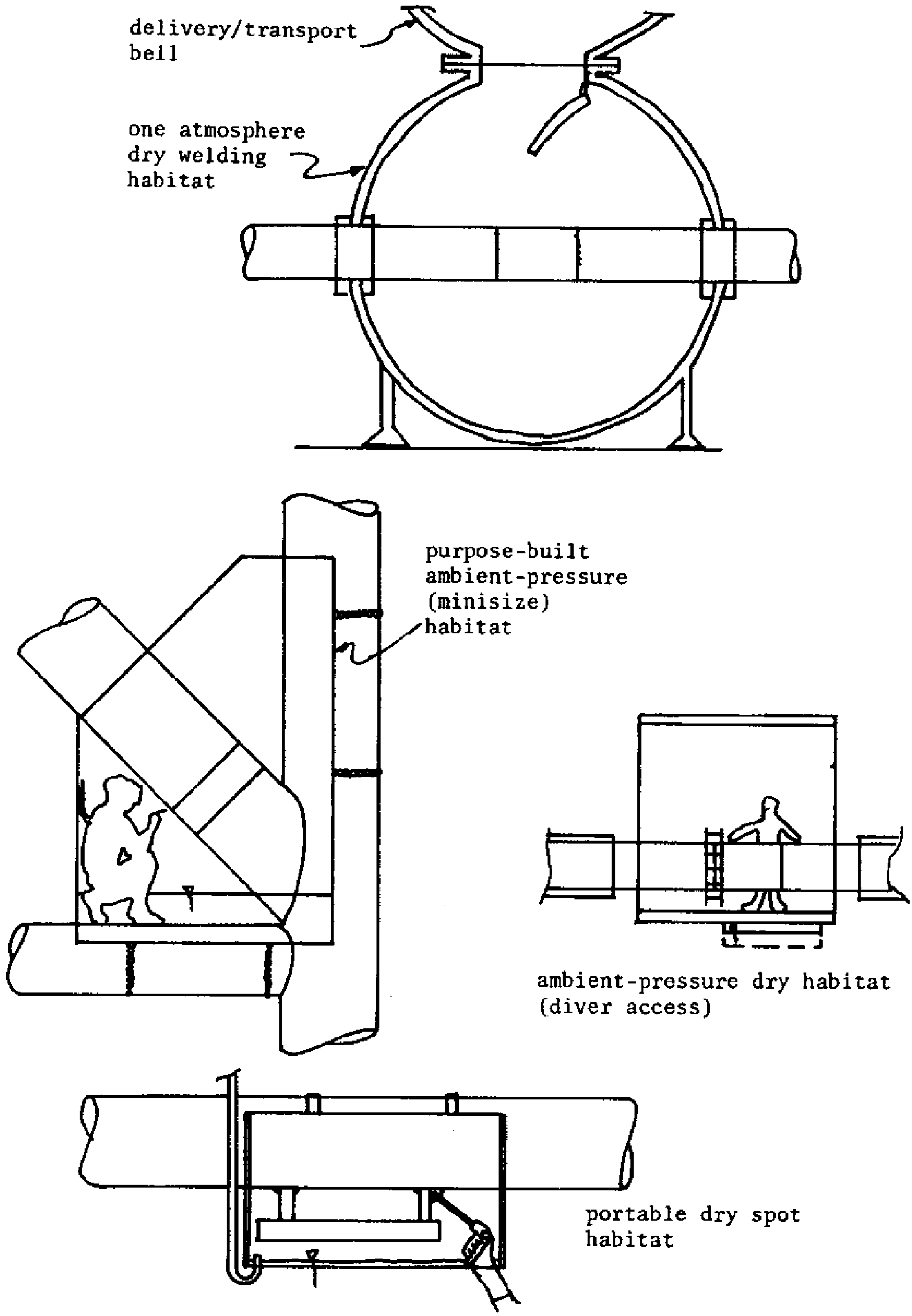


FIGURE 3.8 HABITAT CONFIGURATIONS

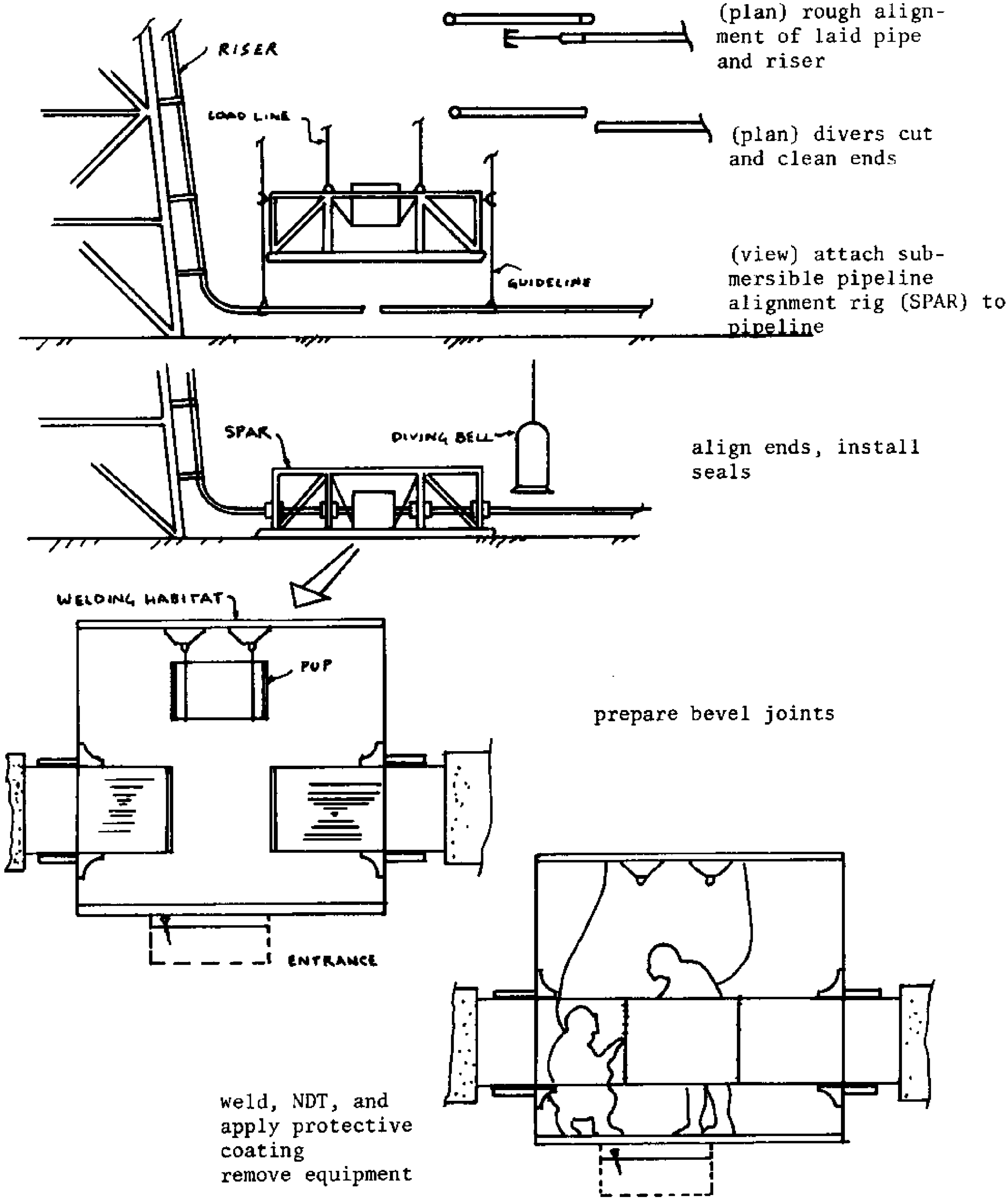


FIGURE 3.9 HYPERBARIC WELD TIE-IN (TAYLOR DIVING AND SALVAGE CO., INC. METHOD)

Submerged Pipe Alignment Rig (SPAR) or temporary alignment frames, depending on service/diving company method

- installation of habitat and support systems
- perform final alignment, install internal pipe seals (stopper pigs)
- preparation of bevel joints with special equipment, and measure to determine "pup joint" length required
- complete pup on surface or in habitat
- perform welder qualification coupons if needed, then upon approval perform weld
- perform NDT test requirements
- apply protective coating, taping, etc. Dismantle equipment

These steps are typical of the kinds of tasks that are involved with pipeline tie-ins and repairs. As is evident these tasks are diver orientated and do not offer much potential for partial automation or teleoperation. The deepest tie-in to date in "real" test conditions has been at a depth of 316 meters, in 1978. This was during a multimillion-dollar test program in which (the initial stages in Norway) two divers lost their lives, possibly by breathing weld by-product gases, due to unsatisfactory face/breather seals. It did however prove the viability for producing welds of satisfactory quality at that pressure.

The various modes of access for habitat welding all require manual or semi-automatic welding techniques, (semi-automatic only refers to the wire feed process). Pipewall thicknesses are as large as 1" for a 26" or 36" diameter pipeline. There are not presently any fully automatic techniques or hardware that will reliably perform this type of weld on the sea bottom. It appears that people will be involved on the bottom for this work whether in one atmosphere habitats, or ambient pressure habitat. In may be noted that hundreds of hyperbaric welds have been performed to date, primarily in North Sea fields. As pipelines go deeper, the use of ambient habitats are ruled out. One atmosphere habitats are really only in the developmental state, although well along in development, and will be used in depths as deep as 1,000 meters when available.[10] (This refers to the planned capability of the new COMEX "Weldap" one atmosphere dry habitat). However, the actual timetable for this capability is not known. A current (1980 Phase I completion) trans-Mediterranean pipeline project is being conducted through limited areas of up to 2,000 feet of water. For portions of this line that will lay in over 1,400 feet of water, (not a large distance, but it is there) the consortia of constructors plan to re-lay any sections that may be buckled during the laying process by going back to shallower areas to start up again. This is in lieu of attempting to perform any repairs in these depths. This costly solution is the only current option.[11]

Other means to accomplish the tie-ins include the use of mechanical or flanged connections. Flanged connections are only suitable for limited service conditions. The procedure used is roughly as follows. The use of a conventional flanged connection mandates a delay between the time that the pipeline is layed and the riser/pipe end relative positions are surveyed by submersible or divers. When the actual dimensions are known between the two flange faces, a partially completed spool piece onshore is completed to the final dimensions and sent offshore. A spool piece like this may be on the order of 100 to 200 feet long and includes expansion bends. They require the use of a crane or winch system to be lowered to the seabed and into the final position. Divers are used to assist the final placement. Flange alignment/mating sleeves are utilized to minimize the final fit up motions, and guides on the pipeline and riser may be incorporated for a smoother operation. Swivel ring flanges are sometimes used on the riser side to allow for rotational alignment. The bolted flange, with its gasket, is not completely finished until the pipeline end of the spool connection is made since this is sometimes a welded connection. After that the flanged joint or joints are finished by using hydraulic bolt tensioners, devices that allow the proper tension to be applied to the bolt prior to torquing the nuts, and assure equal loads all around the flange. This work is diver intensive and requires complex manipulations, and positions that are not possible by other access means.

Another mechanical means for tie-ins are the weld-ball techniques, where a Weld-ball assembly (Weld-ball is a BOC Group trademark) is fillet over the adjacent pipe ends and fillet welds are carried out (as opposed to butt welds for most hyperbaric welds). This is intended to allow for fast fit-up and less severe alignment requirements. They are used for new tie-ins, emergency repairs, and permanent repairs.

A third mechanical tie-in method is the Hydroball/Hydrocouple method (a product of Hydro-tech). This uses a locking socket/ball arrangement and uses bolts to avoid the need for welding. At least 260 of these devices have been installed prior to 1979, usually with acceptable results.[12] As with regular flanged connections this system is diver intensive, but attempts to minimize the difficulties of the tie-in. It does not appear to be at all amendable to ROVs or manned submersibles.

A very new technique is also in use, marketed as the "Star-couple System", which is a cryrogenic soupling. The system operated as follows, and uses a habitat similar to that for welding (dry and choice of pressures);

a coupling/sleeve consists of an outer casing of a nickel titanium alloy, which acts in the reverse way to most metals, it shrinks and contracts when warmed/heated. The couplings are kept in liquid nitrogen to keep them at a low temperature. When the coupling gets to the dry habitat it is taken out of the container of nitrogen and fitted over the two ends of the pipe before it has a chance to heat up and contract. When it does contract it provides an acceptable connection. These are currently limited to 8" diameter, but have been used successfully in numerous sizes.

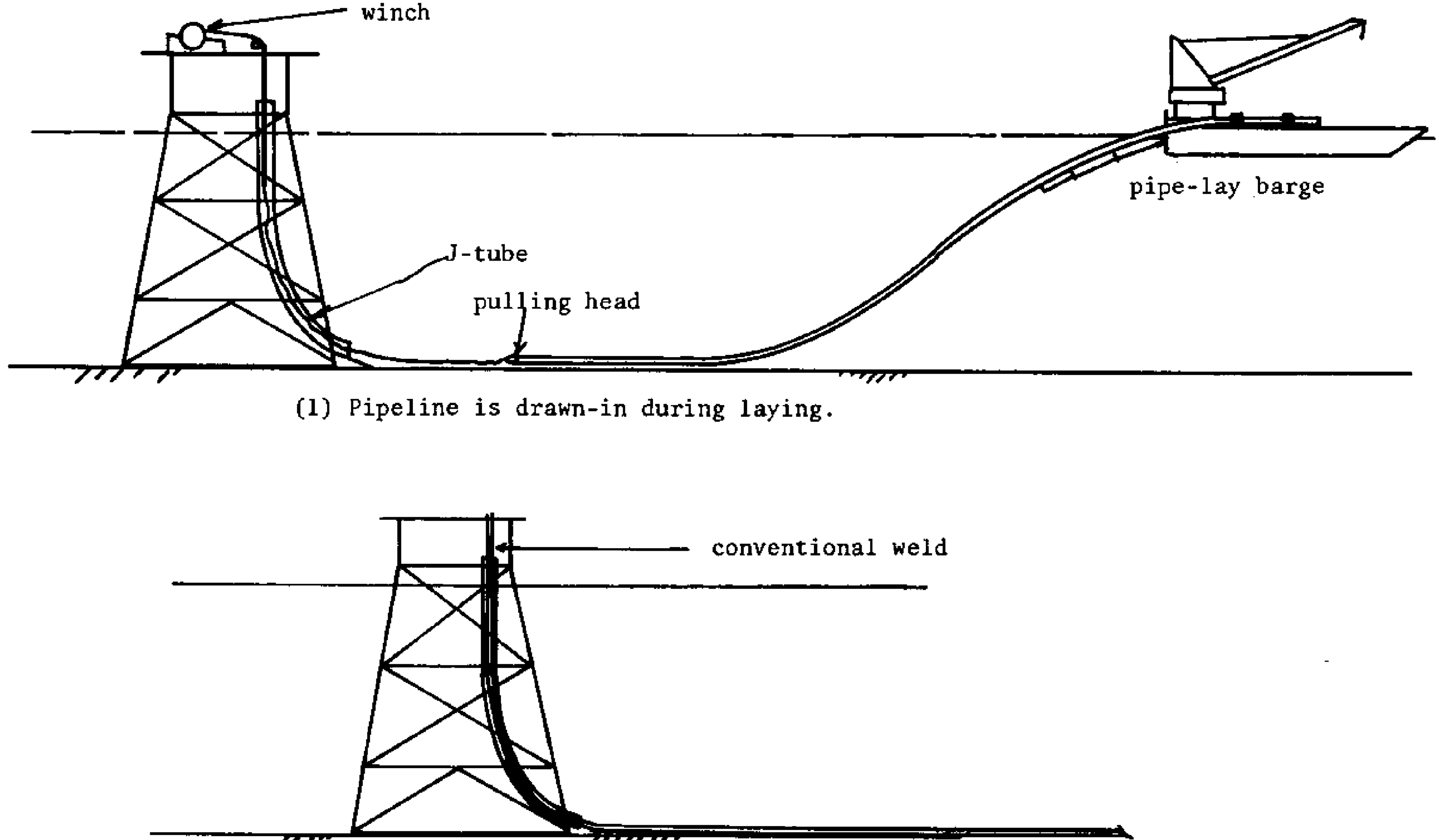
Pipeline laying and tie-in work has been a large user of divers and saturation systems. In the Mexican sector of the Gulf of Mexico, one construction/diving company performed fifty hyperbaric welds during 1979 alone. Although these were for the most part in depths of less than 250 feet, the amount of saturation diving involved is substantial. There are feasibility studies and model/prototype automatic diverless methods discussed in the literature. They do not appear to be near fruition. Smaller diameter lines are now installed on subsea completions using "diver-less" systems, where a hydraulic system is used to clamp-in the socket of the pipe-end once it is pulled into a receptacle. The method appears to be limited to smaller diameters, and although it will play a part in deepwater satellite wells and some larger systems, the technique has not been reported to be used in conventional situations, such as with larger diameter lines.

The second major method for making a tie-in is to utilize J-tube pull-ins, or one of the techniques along similar lines to them. These have been used successfully on North Sea and Gulf of Mexico installations, and are useable on fairly large diameter lines. A platform is designed to use this technique by installing guide tubes through which a wire rope cable is used to pull in the flowline/pipeline as it is layed from a reel barge or lay barge. This requires a diver to make up the pulling head connection, but reduces the need for underwater intervention since all of the welds or flanges are performed on the platform above water. The general set-up used is shown in Figure 3.10.

Other new or proposed tie-in techniques are performed by purpose built vehicles or systems (see section 7.3). These are diverless systems and are primarily new methods that were design for deep water use. This distinction is in contrast to the conventional welded or flanged methods which were basically upgraded versions of shallow water techniques that were developed in the Gulf of Mexico and then upgraded when they were applied to the North Sea situations, primarily larger diameter pipelines, and deeper waters. The conventional methods appear to be at the limit of their depth capabilities and because of this newer methods are being tried. Although most of the major North Sea trunk lines have been completed, a major project source in the future will possibly be installation of parallel gas lines, mandated by enforcement of UK and Norwegian requirements for using gas, rather than burning it off. This may usher in a new set of lines that will utilize some of the more or less new techniques on a major scale.

3.2.4 Subsea Production Systems (SPS)

Subsea completions for both central and satellite production units have been in use since 1962, on a limited basis. There have been a total of 120 satellite units installed as of 1979, with an additional 15 subsea trees installed using bottom templates. Of the 120 satellite SPSs, 34 are offshore of California, 26 in the Gulf of Mexico, and 24 have been installed in the North Sea. 30 more have been scheduled for completion



(1) Pipeline is drawn-in during laying.

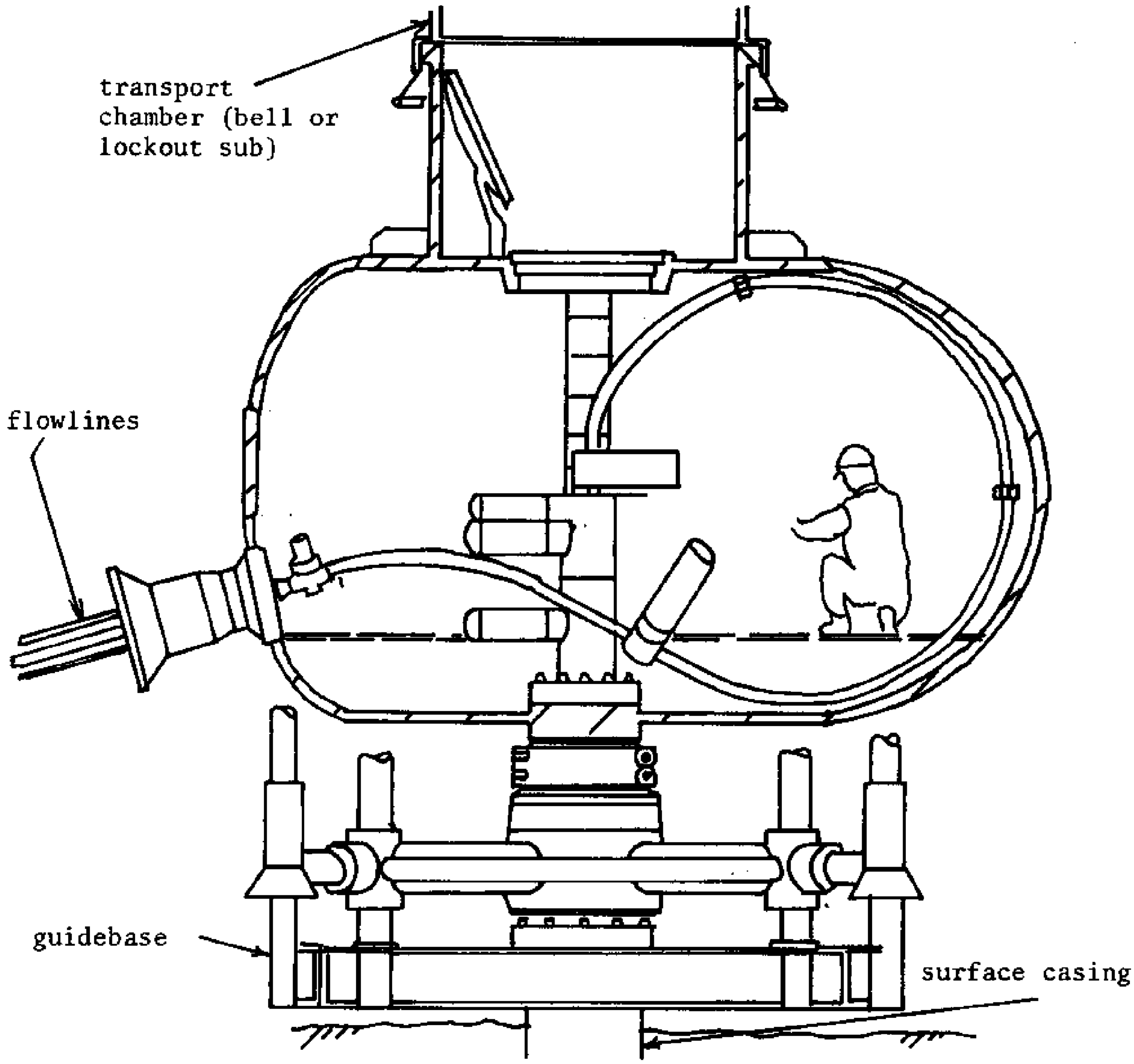
(2) Complete weld above waterline.

FIGURE 3.10 J-TUBE RISER ARRANGEMENT

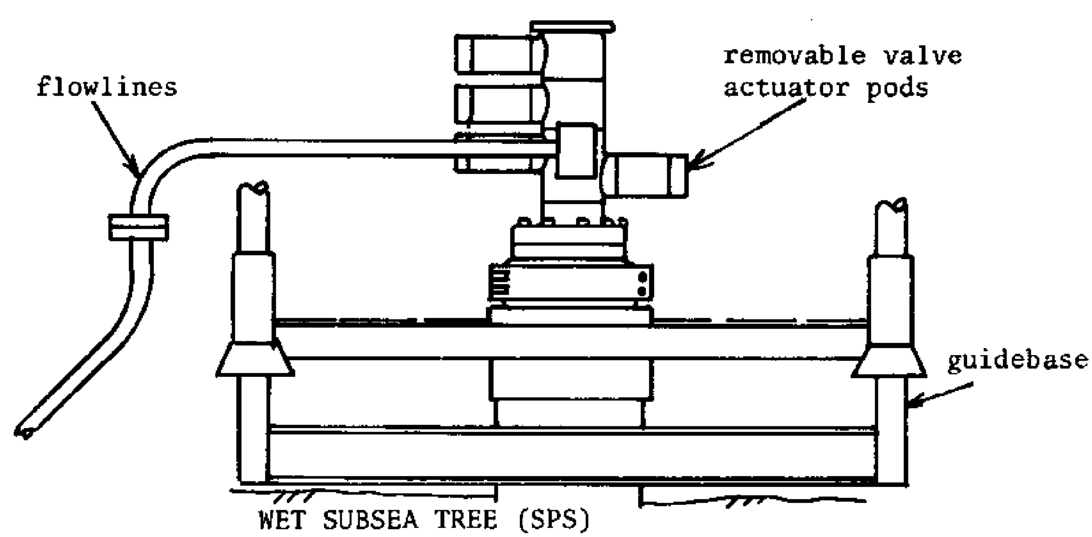
in 1980-81, half of these for North Sea fields.[13] An SPS is essentially a valving arrangement installed at the wellhead on the sea bottom, with small flowlines running to a floating/tethered loading facility or to a gathering platform. The SPS is designed to allow the use of Through the Flow Line drilling tools (TFL) and to allow workovers of the well by re-entry from a floating vessel above the SPS, similar to exploratory drilling. These allow for rapid field development (since some have been delivered within 3 months of ordering), and are used for marginal field developments or with semi-permanent floating production facilities. The first oil to come ashore in the UK sector was via a floating production system utilizing an SPS, at the ARGYLL Field, with a converted semi-submersible drilling rig as the floating facility.

The general arrangement of a SPS follows two designs, the wet tree and the dry tree. The wet exposed tree, lately installed in conjunction with a protective frame in exposed areas, (to reduce damage potential from fishing trawl boards, etc.) is in wider use. The dry tree, less widely used, and initially more expensive, utilizes a pressure vessel to enclose the well-head and its associated controls and manifolds. The wet type is exposed and accessable by all means of underwater intervention, while the dry type utilizes a dry transfer capsule for personnel access (basically a type of diving bell or MDU arrangement). Typical configurations for both types are shown in Figure 3.11.

The dry type is essentially diverless after initial installation is completed. The wet type is accessible by many means and will require intervention for servicing. For depths of less than 1,000 feet of water, SPS costs may be competitive with conventional steel structures, at least for the North Sea environment. Dry systems have been cited as



LOCKHEED ONE ATMOSPHERE DRY WELLHEAD CHAMBER



WET SUBSEA TREE (SPS)

FIGURE 3.11 SPS - WET AND DRY TYPES

safer since a containment of a leak is possible, but there is no consensus on this. The dry system allows for the use of nearly conventional above water servicing techniques for valves, hydraulics, and controls. Most systems are designed for very high reliability and a variety of control methods, normally incorporating a back up system, are in use, including accoustic telemetry of signals from the central platform. Needless to say the desired access levels are minimized (for design) but how well these are achieved in practice remains to be seen.

The underwater intervention for the wet trees is similar to normal exploratory drilling support and is primarily a matter of replacement of the valve hydraulic actuators, along with power source and control component replacement. Tasks supporting operation of these SPSs appear to be fairly adaptable to the use of ROVs or at least manned submersibles, however this would apply to the newer designs which have yet to be employed on a wide scale.

Flowline tie-ins for SPSs are performed with systems that are integral to the SPS, and simplified as far as possible. These use mechanical connections, and are designed for use in deeper waters without diver access, although they are performed by divers.

The successes in use of the SPS methods are mixed, and the vast amount of diving associated with SPSs is widely quoted. System costs are not really known yet for the deep water types since the more sophisticated types have no service records yet. Well work-overs require a surface drilling vessel, and have been the source of major operating costs. One source stated that a major SPS will require a dedicated semi-submersible. Reliability of wellhead controls is still a large problem and repair is a diver intensive operation. The complete underwater field includes the use of

Manifold units which may be isolated for servicing or replacement.

A major operator of North Sea fields noted that the jacket solution is a much easier operation to manage because of the familiarity of all of the surface techniques for production components. Major operators are all involved with some SPSs, usually by including them as satellites to a major field, and much of the work to date has had system evaluation as a primary or secondary interest, for long term planning for deeper areas. Deepwater prototypes are also in place providing realistic test conditions for diverless systems, but using relatively shallow locations that allow for diver assistance for test/de-bugging purposes.

The SPSs are used in conjunction with smaller flowlines and include the use of Coflexip piping. A future field configuration with solely SPS production is shown in Figure 3.12.

The magnitude of underwater work for this type of development is not necessarily more than that associated with conventional jackets, etc., still the recent installations have been much more diver intensive than anticipated. A diving industry source referred to diverless SPSs as the best work that divers have had. A recent SPS installation on the ARGYLL field required 24,000 man-hours of saturation diving and several hundred bounce dives to complete the installation. This only represents the initial requirements since further work is required for servicing and for rig removals. This may be compared to the amounts of diving listed in Table 3.3 for the COGNAC installation. Similar large amounts of saturation diving were utilized on the BUCHAN field in 1979 to complete its SPS system.

Sophisticated diverless SPSs have been installed (prototype only) that utilize a dedicated manipulator system. These are prototypes and not in regular use. They are, however, designed for eventual use in depths

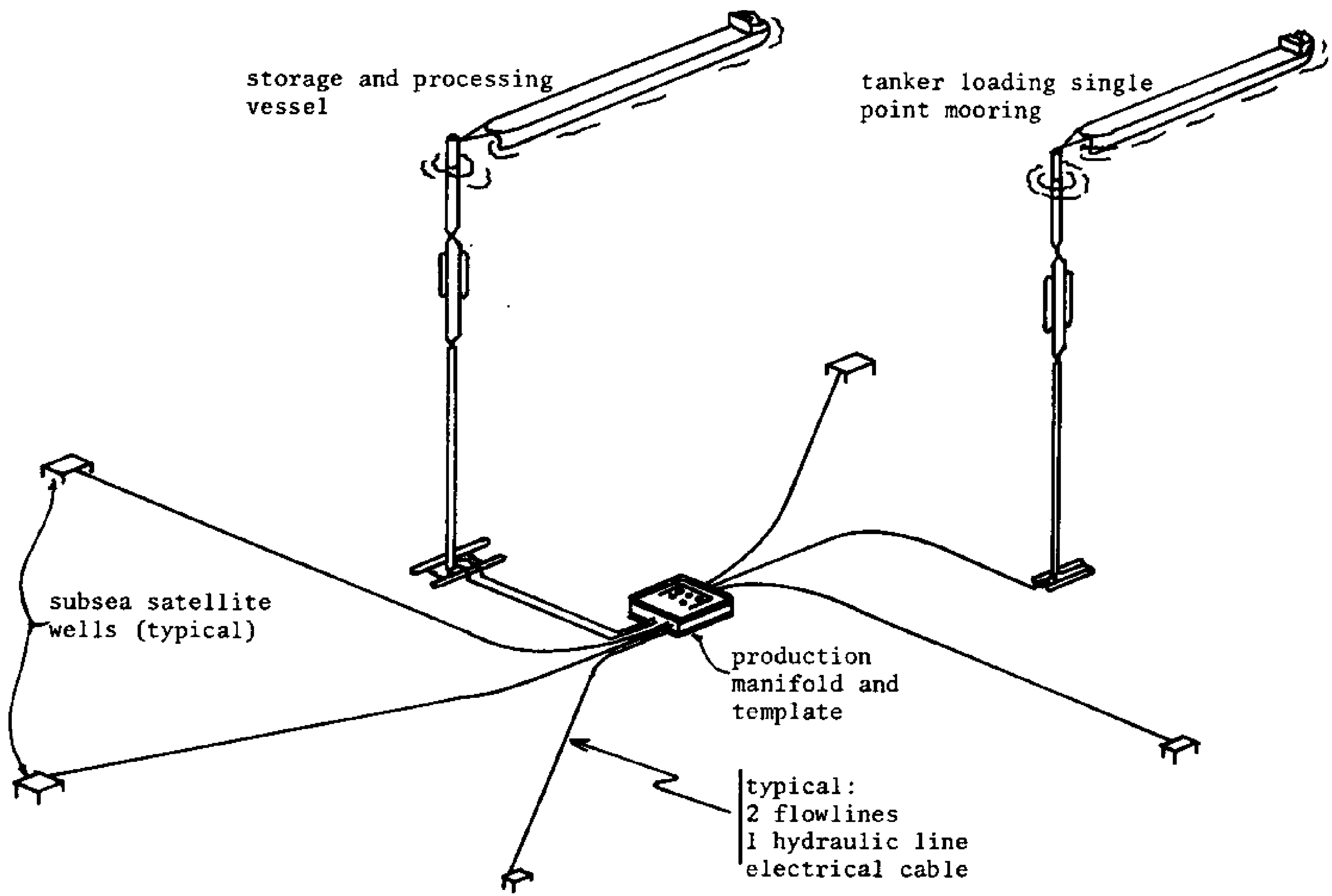


FIGURE 3.12 FUTURE FIELD - SPS SYSTEM

up to 2,500 feet, without any ambient divers and have proved the capability exists for such production.[14]

In the meantime fields with marginal reservoirs or needs for minimal investment will utilize SPSs. A recently applied Gulf of Mexico technique normally suited for shallow waters has been proposed for the Northeast Frigg Field. This will utilize a subsea production system on the bottom and a small jacket of simple design above this. The jacket will be used for servicing and communications/control equipment and will not have processing equipment. This will avoid the construction and maintenance of a major structure and at the same time avoid the need for a semi-submersible throughout the field life.

Although the underwater intervention methods for SPSs are not completely defined, they parallel drilling support and offer a potential for elimination of most of the diving tasks associated with large structures.

3.2.5 Underwater Inspection and Monitoring Activities

3.2.5.1 General Requirements and Background

The regulatory and non-operational considerations of inspection of structures are dealt with in detail in section 6. The purpose of this section is to determine the operational aspects of the underwater inspection and monitoring activities and to determine the role of the various means of access by which these activities are carried out.

Inspection may be directed towards fixed platforms, subsea completions, loading systems, pipelines, and risers. These types of structures comprise the permanent installations used by the offshore oil and gas operators. The underwater inspection of mobile and other non-permanent structures or vessels is excluded from the discussion. For all of the permanent structures there are three general categories of inspection:

1. Post construction inspection
2. Routine and Certification inspection
3. Post repair/modification inspection

The first and third categories are there for apparent reasons. The second type, the routine and certification motivated inspections, are carried out in order to allow the operator to determine and maintain the assurance that the structure involved is sound and able to carry its design loads or actual operating loads in the manner necessary to maintain adequate safety of operations.

Although inspection and monitoring may be concerned with non-structural items, such as hydraulic or electrical systems, the overwhelming amount of work in the inspection and monitoring of underwater structures is concerned with structural integrity of platforms, pipelines, and risers. Few other tasks are performed underwater on such a regular or prescribed basis throughout the life of the structure or facility.

Non-structural inspections are carried out underwater but these are not normally considered as a major area of work for any mode of access, and comprise a very small percentage of the actual underwater activities needs. This would, however, include the inspection of underwater hoses, flexible joints (such as cardan joints, swivels, and universals on loading structures), and other special cases.

Although the major amount of the underwater structural inspection is performed to satisfy regulatory certification requirements, much of this work would be required regardless of the statutory requirements, in order for the operators of the major structures to maintain adequate information levels on the design performance of structures. Additionally, some of the data is used for future needs for newer types of structures. This has been the case in the North Sea UK and Norwegian sectors, but will be more and more the case in other areas of extreme environmental conditions and with the introduction of newer designs. For this reason the levels of inspection needs is expected to increase in some US OCS areas.

Structurally orientated inspections are carried out on an event triggered basis (such as after an extreme storm or after an accident) or on a regular basis. The regular annual and five-yearly requirements for maintenance of certificates of fitness of structures required by regulations in the UK and similarly in Norway, are by far the most stringent imposed on operators in any area. At this time they are a major source of the work in the regulatory-based inspection category. Appendix E describes the statutory requirements for underwater inspections for the US, UK, and Norway.

In order to maintain the certification of fitness for either the UK or Norwegian sectors, the operator of an offshore structure must perform a certain amount of general and detailed inspection and monitoring of the structure. This sometimes includes non-destructive testing (NDT) on a limited basis, primarily at design determined high stress areas, or areas of observed problems during the life of the structure.

The inspection of offshore steel and concrete structures are of a different nature (beneath the waterline) and are discussed separately for this reason. Other structures such as loading systems are inspected along the same lines as the steel platforms and are not discussed. Pipelines and risers are treated separately, reflecting the regulatory treatment of their inspections. The inspection of subsea production systems has not been well documented to date. These systems do not have any major structural components, but some of the newer more complex ones, such as the one-atmosphere dry type SPSs, have a pressure vessel configuration that may require a form of structural inspection. However, since these types are relatively recently utilized and there is no data available, this aspect of inspection is not accounted for. It may suffice to say that these devices are checked periodically to determine if any (visibly detectable) damage has been sustained. If so a further inspection may be carried out as necessary. As previously noted, newer SPSs are now being fitted with protective cages and these will surely show any type of trawling or other damages. The status of periodical and certification orientated inspection of SPS was not investigated, although these installations may account for a considerable amount of diving and other mode of access work in the future.

All underwater inspection and monitoring is limited to the following tasks. The general visual survey is the predominant task. Certain amounts of cleaning are required for inspection access and for helping to maintain low wave forces on marginal design structures. NDT techniques are performed on a limited but critical basis. The major component of maintenance of structural integrity is the monitoring of the performance of the cathodic protection systems, usually by performing potential surveys.

The following discussion provides background information on these general tasks and systems. Following this is a description of the inspection and monitoring tasks that are involved for the particular types of installations.

Cathodic Protection Systems

The assurance of the integrity of submerged structures and the submerged portions of offshore steel structures and steel components of concrete structures is a matter of ensuring that the members are intact and do not suffer from corrosion or fatigue induced degradation. The various design criteria for these structures usually require a corrosion allowance for the possibility of corrosion and the loss of wall thickness or member thickness due to corrosion. For steel structures this is an expensive and inefficient method for providing a margin of safety, and becomes especially undesirable for deeper water structures that cannot afford excess member sizing.

In order to limit the corrosion allowance requirements, offshore structures are protected from general and local corrosion effects (such as corrosion fatigue, weldment corrosion, and crevice corrosion, etc.) by cathodic protection (c-p) systems. By using cathodic protection systems the electrochemical potential between the steel and the surrounding sea water is depressed until the steel surface is the cathode of the galvanic cell which is set up. Only the cathodic reaction (i.e. oxygen absorbtion) will take place on the steel and the anodic dissolution (corrosion) will be retarded. This is accomplished by supplying an external current source (working against the normal galvanic reaction of the steel in the seawater) which may be sacrificial anodes or a rectifier and inert anodes (impressed current). An example of the resulting current flow for a section of a structure is shown in Figure 3.13. The limit on the desired steel potential is the reversible limit for the production of hydrogen, which if present will cause the formation of hydrogen at the steel surface. This may cause hydrogen embrittlement to occur which will aid fatigue crack propoga-

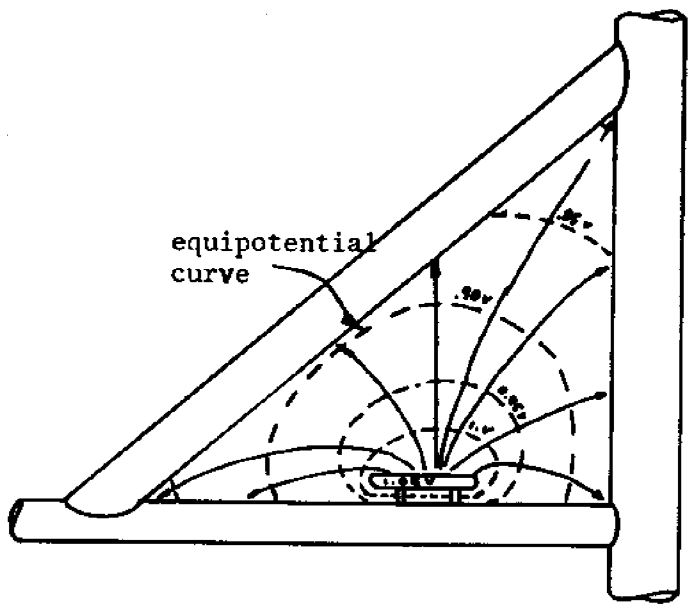


FIGURE 3.13 CATHODIC PROTECTION CURRENT FLOW

Source: Based on G. Valland and S. Eliassen, "Monitoring of Cathodic Protection Systems," Proc. 11th Annual OTC, 1979, p 2127.

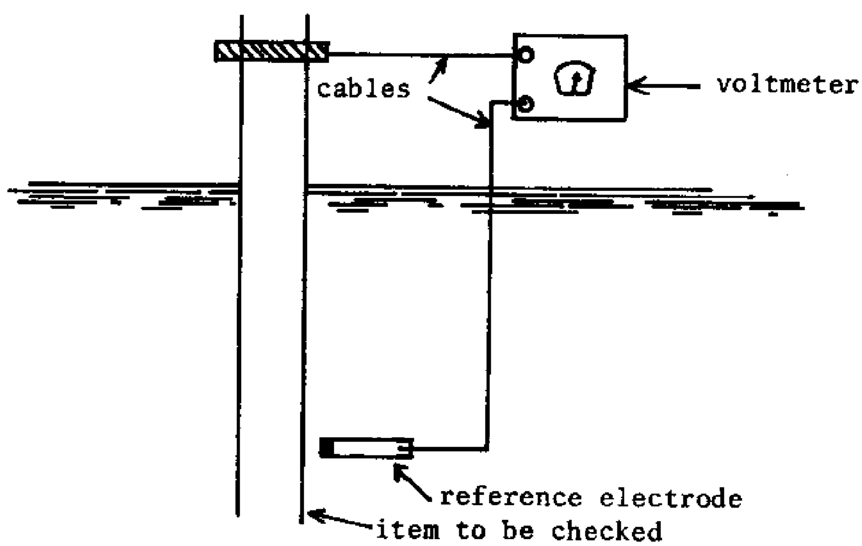


FIGURE 3.14 POTENTIAL SURVEY - PROBE METHOD (SCHEMATIC)

Source: Based on G. Valland and S. Eliassen, "Monitoring of Cathodic Protection Systems," Proc. 11th Annual OTC, 1979, p 2127.

tion. For this reason the desired potential has a limit. This causes practical problems since the actual geometry and positioning of the inert or sacrificial anode will cause uneven potentials. This adds to the need for determining the in-place local condition of the cathodic protection system, and for the monitoring of the system to determine baseline conditions and operational logging of the system performance.

Monitoring of the system performance is a critical element in underwater monitoring of structures. The general condition of the impressed current system must be examined to ensure continuity of wiring, etc., and these types of systems are notorious for underdesign and failure due to damage in the splash zone. For both systems, impressed surrent and anodic, the monitoring of the system is carried out by potential surveys. This requires measurement of the potential between the anode and the structure to ensure that an adequate potential and current is present. In addition to this the anode may be measured to help estimate the rate at which it is being used. This will help in determining whether or not the structure is properly polarized and also help to determine design data.

The potential measurement may be carried out by the use of a hand or manipulator held probe, which provides approximate indications of the local system condition. The actual effectiveness of the system is influenced by local effects of the structure, and because of this a large amount of measurements must be taken to accurately assess the c-p performance. This is especially true for the more critical locations of the structure, the highly stressed node, which present an access problem for all but the smallest vehicles or divers. In order to make a measurement the surface will require some local cleaning, but only for the point of probe contact.

In addition to the cathodic protection systems, some operators, but few, have utilized a structural coating of coal tar epoxy paint, which is used in conjunction with the c-p system.[15] The main reason for the coating is the di-electric effect of the paint which helps to provide a more even current spread. This is vital in providing protection in the difficult to reach yet critical areas of re-entrant node angles. The coating will, however, deteriorate, and so the anode design is sized for an estimated percentage of coating breakdown. This has been estimated at 25% to 50% of loss at the end of the planned lifetime of the structure.

Due to delays in the commissioning of the impressed current systems (up to 18 months), some operators have utilized a hybrid system where the structure may have some anodes, sized for a short life, and the long term protection is supplied by impressed current. The use of temporary rope anodes has been reported, where titanium strands have been wound into polypropylene ropes which are suspended down through the splash zone and protect the upper submerged levels of the platform.[16]

A few newer systems have incorporated a permanent monitoring system with permanent reference electrodes installed in critical areas. This will only provide information for the immediate area, but this information will be useful for comparing potentials at different times.

Because of the many unknowns involved in c-p design, especially for frontier areas, such as actual potentials, currents, temperatures, salinity, pH, and available oxygen conditions, it is very important for the operator to determine the level of operation of the c-p system.

During the initial period of submergence it is important to monitor the potentials. The initial survey is important in that it has been shown by practical experiance, that if a steel structure is adequately polarized initially the current requirement will decrease and the anode lifetime will increase. However, if the structure is not well polarized initially corrosion will start and anode consumption will be excessive. It is a general fact for corrosion technology, that it is much easier to avoid initiation of corrosion than to stop propogation of corrosion.

The actual conditions of the c-p system may be determined by measurement of the electorde potential of the structure and by determining the electromotive force (EMF) between the structure and a suitable reference electrode. The actual protection potential is the difference between the voltage measured and the known reference electorde half cell potential. Most commonly the reference electorde is a silver/silver chloride half cell. In practice the reference electrode is a probe and it is positioned near the structure. Figure 3.14 shows the principal of this method, and the actual distance between the probe and the cleaned steel is on the order of 50 mm maximum.

The potential survey may be carried out by the following methods with accurate recording of the positioning being a requisite:

- reference electrode carried by a diver
- reference electrode carried by an ROV
- reference electrode carried by a submersible
- reference electrode lowered from the surface
- fixed reference electrodes

Depending on the mode of access the voltmeter may be located above or below water. The potential measurements require a good electrical contact with the steel, which requires some cleaning and some systems have an indicator which signals adequate contact. One source noted that other more stringent inspection requirements call for joint cleaning and that the disturbances due to the cleaning will cause a localized depolarization of the structure. This is undesirable for both the c-p system performance and will also influence potential surveys taken before repolarization has taken place. Also the use of ROVs and manned submersibles will be potential sources of error in the potential measurements, since the localized thruster turbulence may depolarize the area. The access to the re-entrant node angle will be limited for larger vehicles. Also it has been noted that as the size of the vehicle or submersible increases, there may be current shielding effects.[17] The use of ROVs for this work is increasing and many vehicles are now equipped with potential probes.

When information has been obtained on current densities the life of the anodes may be determined and the rate of anode use is determined to decide whether adequate polarization has taken place, whether all areas are covered, etc. Most offshore steel structures utilize bare steel constructions with adequate protection by c-p. The c-p performance is fundamental to the structural integrity, and monitoring of the c-p system is a routine requirement. Some platforms have had underdesigned systems and have required very expensive retro-fitting. The fitting of sacrificial anodes on the upper 150 feet of the submerged portion of the Occidental Piper platform was done in order to replace the impressed current system which was underdesigned and prone to failure from storm action. Aluminium anodes were fitted to only the upper portion of the platform, thus only in the surface air diving access area, to minimize saturation diving costs. The cost of the retrofit is estimated to have be approximately $17 million. The North Sea learning curve for c-p systems has been severe due to initial use of Gulf of Mexico based potentials, and erroneous estimates for exygen content, along with lack of data on currents at different depths. These types of problems will occur in any new area unless adequate data base provisions are made. For these reasons c-p monitoring will remain important.

Underwater Non-Destructive Testing Methods

Due to the severe restrictions both from operation underwater and with above water quality of information, major operators have made serious claims that underwater NDT is not adequate and that they will not depend on its results for planning/design issues.[18] Still NDT is the only means by which the operator may determine whether or not there is any incipient or have been any fatigue or corrosion fatigue induced cracking. The platforms in the North Sea were installed in a very fast development era, and for the most part the early structures were in depth and environmental regions for which no hard data were available. Also member sizes were required which far surpassed any of those utilized at that time in the existing Gulf of Mexico structures, which required the introduction of new node designs, new steel thicknesses for welding processes, and new fabrication techniques. Along with the inherent problems of estimation of loads, these factors caused a high degree of unknowns to be introduced into the structures designs. The actual and fatigue loading characteristics were not known accurately. For these reasons the highly stressed node areas require a degree of inspection and testing to determine if any cracking has taken place, and will do so throughout their lives. The methods for determining the existence of an incipient failure are not well developed, and certainly less so for underwater usage.

The most widely employed NDT methods for steel and weldments are radiographics, ultrasonics, and magnetic particle inspection (mpi) techniques.

The radiographic NDT method is the most informative and reproducible. Unfortunately, it is the least well adapted to underwater usage. These techniques are not in common use underwater, although they are very widely used in conventional quality control practice, and with onshore fabrication of offshore structures. They are, however, commonly used for underwater habitat testing of welds, such as for pipeline tie-ins, and for repairs to major structural members, but are not used except in unusual circumstances for conventional joint or member evaluation. When employed they are done by divers only.

The use of magnetic particle inspection, is a widely used technique for weldment testing, however, it has not been used to any appreciable extent in the US above or below water. The procedure consists of magnetizing the area to be inspected and then applying (or doing this simultaneously) a liquid suspension of ferro-magnetic particles to the magnetized area. Through proper application of probe positions and polarity, the technique will detect the presence of linear defects in the material. The magnetic particles will align themselves along a crack due to the leakage of the magnetic flux. This technique is quite a rough indicator of the condition but does provide the opportunity to determine if cracks are occuring. Once a crack has been located it may be marked for a later more careful analysis and testing. This method is widely employed for weld inspection in North Sea border countries and in North Sea structures, although not in use in the US. Recently marketed systems are available for operation in depths up to 220 meters, and have DnV approval.[19] The actual record of the mpi NDT is a video or photo recording of the mpi pattern, and because of this, the method requires a highly skilled operator to obtain useful results. A similar method utilizing a magnetic tape has been noted by Busby and may be more amendable to use by manipulators.[20] A more efficient method of applying the mpi magnetizing current has recently been developed, whereby the typical hand held probes are replaced by use of a 6 meter long length of flexible cable to be would around a joint and energized from a surface supplied and operated power supply. This allows a continuous pass to be made around the weld line, using conventional black lights and magnetic ink spraying equipment. The system is orientated for diver use but may be adaptable for submersible or ROV deployment, although no references have been found to that effect.[21] All of the mpi techniques require a clean surface, however, the degree of required cleaning is not accurately specified.[22] However, bare metal is required for this technique.

Ultrasonic testing has been widely used in dry applications and is now utilized underwater. Its primary uses are to detect material thicknesses and for detection and location of discontinuities or flaws in the parent material. It is also used for inspection of weldment. Busby cites two techniques, resonance and pulse. The resonance type is applied from one side of the material only and will yield thickness information. Pulse techniques are of two types, one classified as pulse echo using a single transmit/receive transducer, and another through-transmission type requiring two transducers. Only the former, pulse echo, is used underwater. Diver operated units may have a remote CRT screen on which the probe output is displayed. Newer units are self contained and provide either CRT or digital read out (the latter for thickness measurements only). The ultrasonic devices being offered today are diver orientated but may in the long run be amendable to manipulators. However, they require a very skilled operator and the hand motions on the probe are quite important. Whether or not this would be within the future vehicle stability and control capabilities remains to be seen. Current systems sometimes employ an NDT specialist on the surface to interpret the results. Photographic records of the CRT display provide documentation.[23]

NDT for concrete structures include experimental efforts with underwater application of the PUNDIT unit, which is supposed to be able to detect, by use of pulsed ultrasonic methods, the concrete homogenity, presence of voids, cracks,or other imperfections, and strength related standards.[24] Further reports on its field use have not been located.

The only test method for determination of concrete erosion was cited by Busby as the Fe Depth Meter, used to locate and measure the depth to steel reinforcement; however, the degree to which this device is utilized is unclear. It is possible to deploy it from an ROV or submersible, being of a probe type design.[25]

A method which may have future applications reported by Busby is the accoustic holography method.[26] Recent reports on the use of this device were not available. The technique is designed to be applied by submersible manipulator or by divers, and may be operated from a DLO. The technique should be applicable to weldments. It requires a very clean surface and its main application will be to locate flaws and then provide a three-dimensional viewing capability, utilizing an accoustic source and sophisticated data handling and storage systems, for both real time and for permanent record.

The above methods comprise the available or near available methods for performing underwater NDT. All of them require a clean surface, at least to bare metal. In most instances the cleaning of the surface requires more time than the actual NDT. Cleaning is also performed for general inspection purposes, since much information is gained by the visual examination performed by a well trained NDT diver. Busby has cited this as a viable method for inspecting both concrete and steel structures, and it does provide information on corrosion damage, concrete spalling,etc.

Cleaning in support of NDT or visual inspection is almost always required. This may be accomplished by use of special high-pressure water jets (with or without grit), needle-guns (essentially a type of mechanical chipping hammer), hydraulic grinders, brushes, and scrapers. In addition to these methods, there has been research and some development carried out in the US on a cavitation water jet cleaning technique. This work has been carried out by the US Navy, ONR. The type of system appears to be of value for removal of ship hull fouling, and also may have application for underwater structural cleaning in support on NDT.[27]

3.2.5.2 Structural Inspection of Steel Jackets and Concrete Platforms

Steel Structures

Although there is variance in the frequency and the content of various operators' inspection programs, they all to some degree are comprised of the following tasks:[28]

1. general visual inspection of most or all members (depending on the structure). Internal nodes may or may not be considered as similar in condition to the external or perimeter nodes, and as such are not always subject to the same frequency of inspection.

2. close visual inspection of a representative selection of the nodes (frequently 10%)
3. non-destructive testing of a selection of these nodes as indicated by the close visual inspection or by design data.
4. wall thickness measurement where necessary.
5. a survey of the corrosion protection system.
6. preparation of a scour diagram.
7. inspection of the risers (and possibly the conductors).

It has been reported by a recent survey of inspection practices in the North Sea that "it is now general practice to devise a single inspection program that is sufficient to meet the requirement for both certification and operational assurance. It is also clear that they have decided to undertake a series of four annual surveys which is intended to be adequate for re-certification without the need for a major survey in the fifth year."[29] It is noted that this will provide a steady load of inspection work for the contractor associated with a particular platform.

The surveys are conducted under the surveillance of the Certifying Authority. In most cases this will actually be a classification society which is operating on behalf of the governmental Certifying Authority. An example of this would be the role performed by Det norske Veritas, which is carrying out survey and certification work on behalf of the Norwegian Petroleum Directorate.

The operational aspects of the inspection of steel jackets include a consideration of the modes of access, the preparatory work necessary to accomplish the primary inspection, and the various inspection tasks. Although the three categories of inspection are at different stages of the structures life, the majority of the underwater work is very similar, except for the marine growth considerations. Post installation inspection will also include some recording of settling data prior to pile completion. A record video may be made to establish as-built conditions, especially for piling grouting overflow, and pile cutoffs. Cathodic protection system surveys are made to establish baseline data. Many times some anodes have been lost during the jacket tow-out and launching, and these are documented and replaced. Impressed current c-p systems must be examined to establish whether the conduits are intact, and documentation of any damage must be made. The post-installation tasks overlap with construction activities but nonethelesss include some degree of documentation for possible purposes of contractor liability and completion.

Periodic inspection tasks are described by the above seven categories. During periodic inspections, a major aim is to establish good documentation of the items which have been inspected. This has lately included comprehensive data management efforts, to allow for good records for the various parts of the structure. This has been aided by recent inclusion of annotation on video tapes, along with increased usage of still photos to establish a permanent record for all of the critical members/nodes.

A stringent inspection program has been required by DnV, and has been utilized prior to the establishment of final regulations by the Norwegian Petroleum Directorate. The required inspections are carried out to an extent that is evaluated for each individual installation, taking into account the condition record, the structures functions, the type of c-p system, and the environmental loads.

DnV classes its surveys as Green, Blue, or Red and these surveys incorporate the following:

Green: A general visual survey (using a diver or ROV or manned submersible, the purpose of which is to detect obvious damage. Sometimes requires corrosion potential measurements.

Blue: A survey to detect hidden damages where cleaning is required.

Red: A "Blue" survey requiring non-destructive testing.

Post-repair inspection is to again establish a baseline record for the condition of the repair. Because repair techniques such as grouted joints or mechanical connections are not as reliable as above water (initial) fabrication, the repairs will usually require detailed re-inspection on a regular basis, and as such demand good documentation of condition. Major underwater structural repairs are not well documented, but have been carried out on a number of North Sea structures.[30]

Concrete Structures

Although there are only a relatively small number of concrete gravity structures (13 structures installed as of 1977), this type of design has an important position in North Sea development. It has been utilized for structures that required very large deck loadings and provided a potential for a decrease in offshore hook-up activities. For these reasons, it may be utilized in the future for North Sea structures, and may be found in other severe environments also. These massive structures are relatively maintenance free below the water line, but do require some underwater intervention.

Post-installation inspection includes initial inspection to detect possible damage incurred during the transportation and installation/construction stages. Along with general visual inspection of the whole structure to locate debris or damage, this initial inspection will require visual inspection and documentation for:

- localization of surface cracks in highly stressed areas based on design information
- localization of concrete erosion, primarily in the splash zone
- inspection for corrosion on any steel members, and c-p system control measurements
- marine growth assessments
- inspection of any areas repaired during earlier phases of construction, etc.
- internal inspection if necessary
- seabed inspection for scour, scour protection performance, and settling data; documentation

As noted previously, there are no NDT methods available for monitoring of sub-surface concrete conditions, short of coring tests which have a detrimental effect and are not usually used.

Regular and certification inspection on an annual basis includes the above tasks, along with some detailed cleaning and inspection/visual survey and documentation of concrete erosion in the splash zone. Also these inspections will require photo documentation of the same area inspected during the initial survey.

3.2.5.3 Inspection of Submarine Pipelines

Inspection of submarine oil and gas pipelines is carried out according to the location and type of pipeline. In contrast to platform structures, most pipelines have coatings which provide a ballasting function and a protection function. Different types of epoxy resin, coal tar, and extruded coatings are in use with a concrete outer casing. With all types of coatings there still occur some pinholes or holidays, which allow the possibility of corrosion occurring. Because this will always be the case, pipelines are built with c-p systems similar to those used on platform structures. These also may be impressed current or anodic types, with the anodic type the most common. These c-p systems present the same monitoring considerations that apply to platforms, with the added problem that the pipeline is probably buried, and thus not immediately or economically accessable, without unburing. Anodes for pipelines are of the bracelet type for larger diameters. Smaller diameters, such as the type laid by reel barges, may use straight lengths of anodes.

The most important element in prevention of pipeline leakage, whether by rupture or small cracks, is to ensure that the pipeline is not subjected to long term degradation from corrosion, which allows the pipeline to be in a weakened state, providing a higher possibility that a initiating event, such as severe weather, impact damage, or others will result in a failure of the pipe. With prevention of corrosion as the most important accident prevention mechanism, the c-p monitoring activities are utilized by most operators. It is expensive to locate any corrosion that has occured due to burial and coatings. Potential impacts from dragging anchore appear to exceed the protection provided by coatings and burial, and so the regular general inspections combined with c-p monitoring provide the present pipeline operation safety.

The period between the inspections required varies depending on the country involved, but pipelines are normally inspected on an annual basis, with US practice including flyovers on a more frequent basis to check for evidence of leakage.[31]

The content of the inspection of the pipeline is also determined by the locality. The actual tasks are concerned with visual inspection with video and photo documentation; primarily to establish the conditions along the pipeline route and to determine the stability of the bottom, the location and conditions at areas where artificial support has been provided, and to look for gross damages such as undocumented dents, coating damage, etc.

Buried pipelines may be monitored by identifying where the pipeline is not buried (which is always an occurence somewhere along the sections of the pipeline), and taking potentials on the unburied sections. This will represent the portions of the pipeline that are most suspect for corrosion protection. The measurement of c-p potentials along the buried sections of pipelines is not generally possible because of the inability to contact the line due to weight coating, somastic insulation, and depth of burial.

In response to this difficulty other methods have been introduced with unascertained degrees of success. These include permanent reference cells, with transmitters, temporary cells used to determine the sea water gradient near the line, and a recently introduced current density measurement device.[32] This is accomplished by measurement of the vertical component of the local current density flowing from the anode into the pipeline. By using a computer analysis of the date obtained, the status of the c-p system along the length of the pipeline is established. This is used to detect:

- defects such as breakdown of the pipeline insulation, missing or defective anodes, abnormal cathodic protection current, or anode consumption
- long term evaluation of the c-p protection system, anode life, current demand evolution

The general arrangement of this device is shown in Figure 3.15. This device may be used along with other devices such as burial depth detection methods, and video records, to provide comprehensive documentation of the condition of the pipeline, usually from a submersible or ROV.

Another application of the current density meter has been proposed, allowing for determination of gross defects such as cracks, or excessive porosity, occuring on concrete structures allowing seawater to penetrate the concrete to a depth that the reinforcing steel members may be subject to corrosion. The metal reinforcing rods are usually polarized by the concrete, which provides insulation, so normally no current is necessary to protect the metal reinforcing. Exposed metal such as risers, clamps, and (seldom but possible) exposed reinforcing are protected by anodes. If the internal reinforcing is exposed by cracks etc., a DC current will flow, which may be detected, in an area which would not normally have any (relatively) vertical current component. Although the use of this method has been proposed, reports on its use were not reviewed. This method (utilizing an external imposed current) is illustrated in Figure 3.16.

In summary, for pipelines, the c-p monitoring may be carried out for both buried and unburied pipelines. The data obtained will be subject to interpretation. Unless a gross defect is detected, the use of divers, or other intervention is not reported. The general concern is to make annual

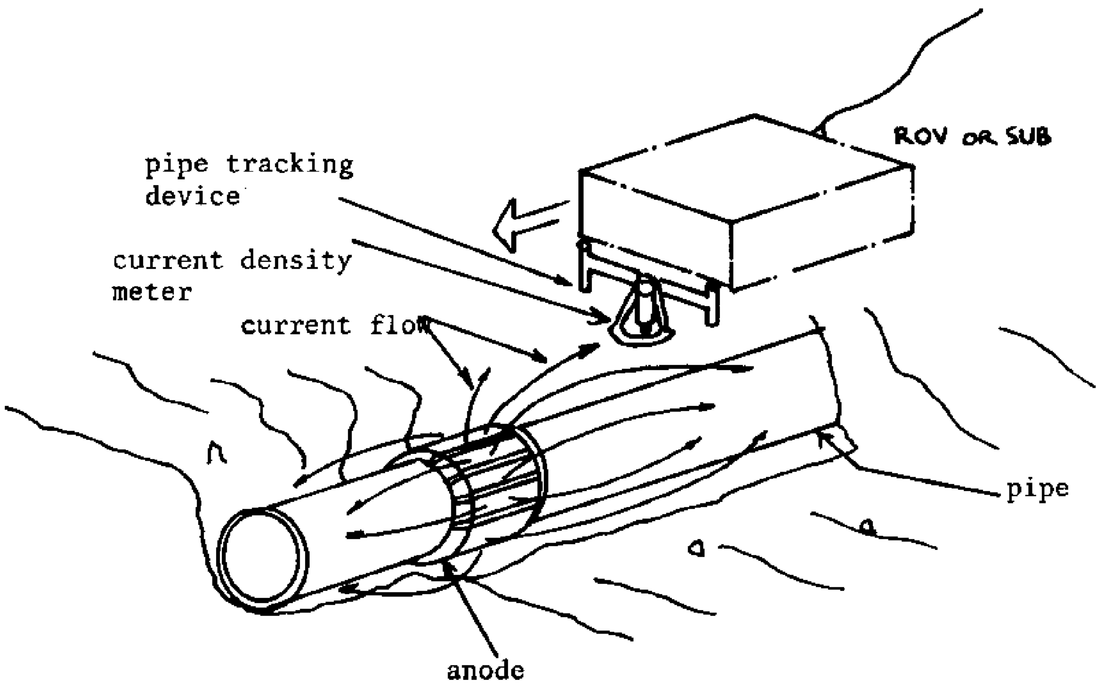


FIGURE 3.15 USE OF CURRENT DENSITY METER FOR PIPELINE

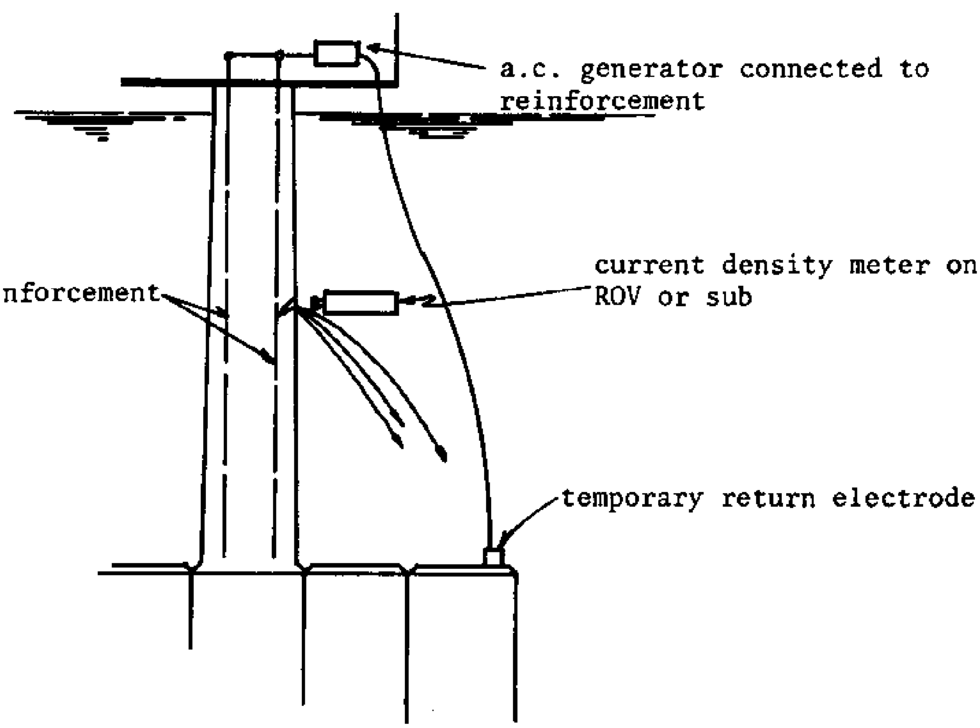


FIGURE 3.16 USE OF CURRENT DENSITY METER FOR CONCRETE STRUCTURE

Source: Based on J-P. Bournat and A. Stankoff, "Cathodic Protection Measurements," Proc. 11th Annual OTC, 1979, p 2120.

or semi-annual surveys to determine if any visible damage has occured, and to follow up on this as necessary. The c-p monitoring may be carried out using manned subs or ROVs.

3.2.5.4 Inspection of Risers

External Risers

External risers are used for steel piled jackets and in some cases for concrete structures, although usually limited to only the lower caisson levels of the latter. The inspection of risers is considered to be a particularly important activity because of the potentially serious consequences of corrosion problems, and in consideration of the location of the risers, which pass through the splash zone, the most corrosive environment of the offshore structure.

The various inspection requirements for risers are of different frequency and detail, with some requirements (such as the DnV) including the riser as part of the pipeline. Because of the exposure of the riser to the atmosphere at the splash zone, along with the potential for damage from a support vessel, risers have incorporated extra protection measures. For corrosion protection this includes use of sheathing compounds, such as vulcanized rubber, coal tar epoxy, monel sheathing, concrete cladding, or other. For protection from physical damage, the riser is positioned carefully and guarded by bumpers, etc, and sometimes may be contained in a carrier pipe or casing, extending from the mud-line to above the mean low water line.[33] In addition to concern for the condition of the riser pipe itself, much attention is paid to the condition of the supports and clamps, along with any potential sources of restraint of the contraction/ expansion movement of the riser.

Inspection of risers in the Norwegian sector has been defined by the Norwegian Petroleum Directorate in the most explicit manner. This includes initial inspection, start-up inspection, and semi-annual inspection. These inspections include the following tasks, which also represent the types of task content that operators are in general interested in obtaining to maintain riser safety, even if on a less frequent basis:[34]

- visual inspection of the riser and accessories to determine localization of mechanical damage, possible metallic waste in contact with or in the vicinity of the installation
- visual inspection of fastening device with testing of torque of the bolts of riser clamps
- visual inspection of anodes, fastening,and potential survey for c-p system
- "control" to verify that riser installation is in accordance with approved design specifications, and to determine position of the riser (these measurements are carried out prior to and during start-up, to establish expansion behaviour of the riser)
- localization of corrosion, with thickness measurements, and photo documentation of areas most exposed
- visual inspection of seabed for erosion/scour with photo documentation
- assessment of marine growth, with documentation and depth level correlation
- visual inspection of flanges and couplings
- visual inspection of fender devices in splash zone for detection of mechanical or corrosion damages.

Riser inspections require access to all depths along the riser, and are diver intensive. They normally require a thorough cleaning along the length of the riser. Work in the splash zone is difficult and dangerous, and is usually performed from a surface supported device. One major diving company reported that its divers were utilized on major structures to provide a follow-up inspection to the work performed by a purpose-built remotely operated cleaning and video riser inspection device, which provided rough information of the condition of the riser, but not enough to satisfy the assurance needs of the operator.[35] This operator, like another major North Sea operator had replaced numerous of the original risers due to severe deterioration during the early operation of the risers.[36]

Internal Risers

Internal risers have been utilized for the concrete structures to bring the risers from the top of the caissons (cells) to the deck level. These risers pass through the caisson/leg and continue inside the leg to the deck. The inspection of these risers is difficult and has not been well planned. They have frequently been installed in legs which have been subsequently flooded, but do not provide any access for large devices, such as divers or ROVs. Although the provision has been made for c-p protection, the way be which these risers will be inspected and potential surveys will be performed is not yet clear.[37]

Riser inspection will for the most part require the use of divers or very well equipped submersibles. North Sea experience has shown that the design of suitable expansion loops, burial requirements, and coatings to ensure riser longevity is not yet firmly established, especially for high temperature service. Until the designs are well established, there will continue to be problems with risers, and this will require a continued effort of intensive inspection of risers. Future platform designs such as the tethered buoyant platform or the guyed tower type will have additional problems with riser design, and so this will continue to be an inspection problem for most areas.

3.2.6 Underwater Maintenance and Repair Activities

The systems which are utilized underwater for offshore oil and gas operations are intended to be maintenance free unless of the type that may be removed for surface repairs or of the type which require the replacement of a component. Typical of this are the valve types used which allow for the replacement of the working mechanism with the body in place, or high reliability components with no repair capability and welded valve bodies.

Permanent equipment does not normally incorporate the types of components that would require any type of maintenance and the term maintenance in usually used in the sense of carrying out inspection and testing to ensure that the systems are in order, although this usually applies to structurally orientated inspections, rather than to equipment or hydraulic/electrical systems, which are rarely included in permanent underwater installation. The exception to this is the sub-sea completion system. However, there has not been any detailed information available on the work involved with their maintenance. They are designed for minimum intervention and incorporate a minimum of operating parts. They are basically sets of valves, and may require some repairs/replacements, but no details were obtained on this. The exception to this is the prototype deep-water system developed by Exxon which utilizes a sophisticated manipulator system with purpose designed valve actuators which may be removed and replaced by the manipulator.[38]

For the above reasons the rest of this section is concerned with the task content of repairs rather than maintenance.

There has not been a large amount of information published on repairs of structures, reflecting operators' reluctance to discuss design errors or accidents. Certainly most structures have not required large amounts of underwater repairs, and the available techniques reflect a lack of previous needs. The concern here is not with shallow water structures but those structures in the deeper Gulf of Mexico blocks and the North Sea.

There have been numerous cases of smaller loading structures which have suffered damage during installation or operation and as a rule these have been removed and brought inshore to be repaired. This reflects the difficulty of accomplishing any extensive damage survey or repairs in deep water.

Permanent structures do not allow this option and have been repaired in place, however, only to a limited degree.

Platforms

When a member has been severly damaged or completely torn off a structure it may be replaced using hyperbaric welding techniques similar to those employed for pipeline tie-ins. This is a costly procedure and requires the construction of a purpose-built chamber, to fit at the node or site of repair. British Petroleum has reported good results with use of grouted repairs of members, where the damaged member is not necessarily removed and a sleeve is fitted over it and the annulus grouted, similar to a pile to jacket connection.

Very often minor damage will occur during jacket installation, piling installation, or due to work vessels, and some repairs will be carried out. A common cause is dropping of piles or pile chasers, or damage to pile guides. Normally some anodes will require replacement after the structure is installed.

These activities require tasks similar in content to installation related activities, and usually employ major diving systems.

Pipelines and Risers

Pipeline and riser repairs have occured on a significant scale and have required the use of the same techniques as original installations, with a considerable number of hyperbaric welds having been performed. Mechanical and welded sleeve repairs are also used for pipeline damages, and many of the repairs to pipelines consist of replacement of mechanical couplings or tie-ins. Pipelines may also suffer from expansion induced anode loosening, however these cases are only recently documented and whether or not this will be a widespread problem is not known.[39] The repairs of risers and pipelines are performed by divers and usually entail a large amount of damage assessment and inspection, some of which may become more possible to perform by ROVs rather than by divers or manned submersibles. The repairs themselves will for the most part be diver work. As the structures installed in the North Sea during the 1970s age there are potentially large amounts of repair to be carried out. A major diving company's record of habitat welding for a period of nearly ten years (1968-1978) indicates that during this period, of the 93 non-demonstration habitat welds performed, 20 involved the repair of pipelines or risers, 5 involved structural member repairs, and the remaining welds were new work, primarily for tie-ins or taps.[40] These figures only represent one company, however, during this period they were the major underwater hyperbaric welding contractor in most if not all areas. This does not indicate the amount of mechanical repairs made (by bolting of patches or stress members, etc.) or grouted types of repairs, but it does indicate the number of repairs to joints critical enough to require a high strength repair, most of which were in the Gulf of Mexico or the North Sea areas.

In general the task content of underwater repairs is similar to original construction tasks. The work is diver orientated, with heavy work conditions. There are large amounts of preparatory inspections, and often a large amount of pressure to complete the job, and the job itself will require heavy work vessels and large numbers of personnel and equipment.

3.3 Summary: Offshore Oil and Gas Activities/Underwater Support

The underwater activities associated with the various phases of the development of offshore oil and gas resources have been detailed and discussed. The quantity of the various types of activity have not been given, reflecting the lack of hard data available in the literature and the responses of major contractors who were contacted. Only rough estimates were obtained, and these were generally based on the service companies own mode of access, primarily from diving contractors. One estimate, for diving only, is given in Table 3.4.

The descrepancy in the equipment and revenues reflects the different manning and man-hours associated with the different activities. Another major diving contractor estimated that 75% of its work was in support of new construction, with the remaining portion allocated to repairs. Still another of the major firms employs most of its divers in drilling support

TABLE 3.4

NORTH SEA 1979 DIVING CONTRACTOR EQUIPMENT AND REVENUE DISTRIBUTION

(mixed gas and saturation capabilities)

Equipment distribution	Gross Revenues	Support Areas
30%	20%	Drilling Support
60%	50%	New Construction (platforms and pipelines)
5%	20%	Inspection and Mainten.
5%	10%	Repairs

Source declines identification. Employs approximately 400 divers (mostly saturation capacity) on a world wide basis.

and construction offering hyperbaric welding at depths to 300 meters. Because of the lack of hard numbers, the actual amount of the activities (say in total man-hours, or other) were not obtained. The next main section of this report will detail estimates of equipment utilization and costs.

Table 3.5 gives some of the more important aspects of the various underwater activities that have been identified in this section, especially those aspects that have safety or cost implications, and notes the means of access that may be used for accomplishing these tasks, along with general operational constraints imposed by general project considerations.

TABLE 3.5 SUMMARY OF CHARACTERISTICS OF UNDERWATER ACTIVITIES IN SUPPORT OF OFFSHORE OIL AND GAS DEVELOPMENT

Pre-drilling Surveys

Depths:	To 2,000 m.
Means:	Primarily surface vessel with towed ROV or survey equipment, potentials for high speed ROVs.
Task content:	Predictable, passive instrumentation/measuring, limited sampling, some core samples by surface techniques/limited ROV use.

Not on critical path, predictable need for activity/schedulable minimum secondary equipment (limited real time data analysis). No secondary costs.

Exploratory Drilling Support

Depths:	To 1,325 m. (63% of vessels capable of less than 305 m, excluding jack-ups).
Means:	Primarily by divers with minimum size systems. Limited use of manned submersibles, ADSs, MDUs. Potential use of ROV for limited task capabilities.
Task content:	Unpredicted/irregular, includes visual inspection and monitoring, light manipulation (simple and complex), heavy manipulation (simple and complex), in combination and singly.

Tasks often on drilling critical path, some tasks are during drilling operations, intervention is irregular and on short notice, tasks are short duration. High secondary costs (drilling vessel). Site access is often in remote areas (with minimal hardware or logistics support), high premium on vessel area use.

Pre-Construction Surveys

Depths:	Platform area surveys - to 365 m, ave. < 200 m. Pipeline route surveys - to 1,000 m.
Means:	Primarily by surface vessel towed devices with limited use or manned submersibles and ROVs.
Task content:	Visual/observation, video/photo documentation, coring/sampling, light manipulation, debris removal.

Not critical path, predictable needs/schedulable. Low secondary costs, minimum assisting equipment.

Platform Construction Support

Inshore- Preparations (Concrete Structures):

Depths:	Less than 200 m.
Means:	Divers, with some manned subs, ROVs.

TABLE 3.5 (cont'd)

Platform Construction Support (cont'd)

Task content:	Visual inspection/monitoring, documentation, some manipulation.

Intervention may be planned but irregular, on critical path for major structures, short duration tasks. High secondary costs for some tasks. Good site access.

Offshore- Tow-out and Immediate Works:

Depths:	To 315 m, ave. < 200 m.
Means:	Emphasis on manned subs with divers for non-observation tasks, additional use of ROV support also.
Task content:	Predictable, also stand-by for irregularities; light and heavy manipulation, observation,video/photo documentation, combinations of above.

Critical path activities occur with high costs and risks, delays potentially expensive. Partially schedulable, weather sensative. High secondary costs.

Offshore- Piling and Immediate Works:

Depths:	To 315 m, ave. < 200 m.
Means:	Primarily divers with construction spreads, large crews, some assistance by manned subs and ROVs.
Task content:	Varies, combinations of rigging heavy/light complex manipulation, observation, video/photo documentation.

Predictable intervention needs, not schedulable, various task durations. Often critical path activities or in support of critical path works. Site environment and access is limited due to timing and difficulties with positions for access. High secondary costs, especially when in conjunction with critical path works using derrick barges, etc.

General Construction Support:

Depths:	To 365 m, ave. < 200 m.
Means:	Primarily by divers (or stand-by diving support), some use of manned subs, or ROV for limited capability only.
Task content:	Predictable but not scheduled, single or combination of observe only, video/photo documentation, light and heavy manipulation, light repairs/minor welding, oxy-arc cutting, etc.

Tasks on and off critical path with access generally on critical path, duration - long jobs with continuous working. High secondary costs. Usually tasks require assisting equipment - cranage, or other special task specific support equipment. Newer systems have dedicated equipment on support vessel.

TABLE 3.5 (cont'd)

Pipeline Construction

Pipelaying:

Depths:	To 600 m, ave. < 200 m
Means:	Divers utilized to 425 m (max.), much surface diving, manned subs and ROVs used for extreme depths and simple tasks.
Task content:	Varies, observation, light manipulation.

Tasks on critical path, irregular needs, not scheduled or predictable, short durations. High dayrates/secondary costs incurred on critical path. Site access/environment - good, with dedicated diving systems on most lay vessels.

Tie- Ins:

Depths:	To 365 m, ave. < 200 m.
Means:	Divers, prototype "diverless" systems (small diameter lines only), use of large construction spreads, manned subs and ROVs used for assistance.
Task content:	Predictable, heavy and light complex manipulation, survey and measurements, habitat welding, use of oxy-arc cutting, NDT, and hydraulic equipment.

Critical path for access, scheduled work, durations are long and continuous. High secondary costs, support equipment. Good access and environment, dedicated systems/vessels.

Post- Installation:

Depths:	To 365 m, ave. < 200 m.
Means:	Divers occasionally, manned subs and ROVs used as much as possible.
Task content:	Observation/documentation (e.g. leak monitoring, "pig" following, route survey) long distances are involved.

Tasks not usually critical path, duration varies, generally short jobs. Minimal secondary costs/support equipment. Good access.

Subsea Completions

(Installation and Operation)

Depths:	To 215 m.
Means:	Reports of "diverless" systems, use of divers, subs, ROVs, in support of setting and commissioning, workovers, some prototype dedicated manipulator maintenance systems.
Task content:	Varies but planned, light and heavy manipulation, observation/documentation.

TABLE 3.5 (cont'd)

Subsea Completions (cont'd)

Installation on critical path, schedulable, durations may be long although not intended. Some secondary costs, possible to carry out from drilling vessel. Few installations for data. Good access.

Structural Inspection and Monitoring

Steel Jackets (Risers similar):

Depths:	To 365 m, ave. $<$ 200 m
Means:	Use of divers, manned subs, ADSs, ROVs.
Task content:	Known in advance, includes, observation, c-p survey, video/photo documentation, measurements, hand and jet cleaning, NDT, complex manipulation, scour survey and mapping, tasks are not necessarily in combination.

Concrete Structures:

Depths:	To 153 m.
Means:	Divers MDUs, manned subs, ROVs.
Task content:	Known in advance, observation/documentaion, c-p survey, some cleaning, minimal NDT, scour survey and mapping, tasks are not necessarily in combination.

Structures - General:

Not critical path, normally carefully scheduled and periodic, long duration with continuous activities, minimal support equipment. Low secondary sosts. Good access/environment - some dedicated inspection systems are in use.

Pipelines:

Depths:	To 600 m, ave. $<$ 200 m.
Means:	Primarily by manned submersibles and ROVs, some liveboating and diving (especially in US), towed devices.
Task content:	Predictable, observation/documentation, some cleaning, c-p survey, route survey, side scan sonar recording, long distance.

Not critical path, schedulable. Good access.

Repairs and Maintenance

Are similar to General Construction.

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4. SYSTEM CAPABILITIES, COSTS, AND UTILIZATION

4.1 System Capabilities

The cost effectiveness of various systems is borne out by the present levels of use. The utilization of a candidate system will be based on the following considerations:

- applicability
- cost of the system
- availability of the system

In the short run there may be a problem with the availability but for general analysis this is not a problem. There are seasonal and cyclical market variances that influence the short term and spot market equipment costs for certain types of systems, but these are transient and do not have any long run influences on the cost effectiveness.

The applicability of the system is the most important aspect for offshore operations. Traditionally these have not always been subject to effective cost-control measures, compared to onshore manufacturing or construction with more accurate cost prediction and a wider selection of contractors. In particular this has been the case for the recent North Sea development where these installations were performed during an era of urgency and at a time when there was a shortage of service or equipment suppliers available at the onset of the projects. Offshore construction and installation operations were carried out by the most expedient means. In this environment, only the applicability and availability of the systems defined what were suitable techniques.[1]

As the activities in the North Sea and elsewhere have become part of a more mature market, the economics of techniques and equipment have become more critical. Today there are often alternative means to carry out an underwater task. While this applies primarily with regard to underwater systems, it may also include some types of surface vessels which have recently been utilized. Examples of the latter are semi-submersible accomodation units, only recently employed in North Sea projects, and not used to any appreciable extent in other areas. As the market for a service matures, alternate schemes are offered. In particular the development of and utilization of alternate means to the diver have become more widespread.

A major determinant of system use is the water depth. Neglecting the extreme depths encountered in a small number of cases, the majority of operations supporting oil and gas development fall within the following depth ranges: the activities supporting conventional platforms are carried out at depths less than 200 meters; drilling support is generally at depths less than 300 meters.

The following depth ranges indicate approximate divisions for current system use and development:

to 50 meters: primarily the depth at which surface supplied air diving or mixed gas diving is competitively prices against most if not all systems.

50 to 200 meters: the range at which most of the current systems are aimed and operated, along with serious cost/capability considerations.

200 to 350 meters: the limits for diving at "economic" costs and the

beginning of the trend not to use divers if at all possible, for cost, performance, and safety reasons. Diving is currently carried out on a major scale in this depth range.

350 to 2,000 meters: the maximum operational depths for offshore oil and gas to date, primarily involving exploration drilling, or predicted to be within the near future drilling capabilities. Special purpose teleoperators or manned submersibles are utilized at all depths over approximately 400 meters.

Most of the offshore underwater activities are in support of field development, and on the average this is in less than 200 meters of water. The following data indicates the volume of work that presently lies in different depth ranges. This directly affects the number of systems being developed commercially and their markets.

Most ROVs and manned submersibles are built to be operated in depths of at least 300 meters, and as such are capable of providing support for activities on almost all offshore fields today. Depth capabilities are not the total determinant of system capabilities, but are a first consideration. The following information is indicative of the industry's current depth capability requirements:

North Sea Field Depths (1977 basis)

48 structures in depths greater than 50 meters

62 structures in depths less than 50 meters

US Areas (major structures only, in use)

300 structures in depths greater than 50 meters

650 structures in depths less than 50 meters.[2]

The deepest range prohibits the use of divers. For less deep situations this is not the case. The most interesting changes in activities are in the 200 to 350 meters depth range. This is where the moves are being made for existing or emminent production systems, to purposely avoid the use of manned intervention by either designing out the process or problems and thus eliminating the need for human intervention, or by designing into the process the ability for tasks to be performed by unmanned means or by isolated manned means such as MDUs or manned submersibles. To date have there been few projects which have included the capability of complex manipulator systems in initial planning of these activities, to later allow for primary maintenance by manipulator.

In the 50 meter to 200 meter depth range the existing structures and equipment have generally been designed for installation and servicing by divers. It is in this range that general and functionally specific ROVs are being used at an increasing rate and where future system trade-offs must be made.

Remote system capability is becoming the subject of increased consideration. Primarily qualitative means are used to describe the actual and potential capabilities of available commercial systems and sub-systems. The root of this discussion is to what degree do the present teleoperators, whether MDUs, manned submersibles with manipulators, or ROVs, have the ability to carry out the tasks that are now carried out by the ambient diver? Then, given a present performance level, how well is the offshore industry using it to advantage?

There is little industry data available that can be used to answer the above questions. Only estimates can be made here. The manipulators in use offshore are, in general, not the state of the art. They are relatively crude and only have a small degree of the abilities needed to substitute for the human hand. Also, the hand is deployed from the body, allowing for incredible maneuverability, sensing, and adaptability for unanticipated tasks. In this context the systems now competing with the diver, especially in the 50 to 350 meter range, are not advanced. They are moving toward more advanced levels at a pace determined by user demands and economics, rather than "technical fix" capability.

Due to the current limited teleoperator capabilities,the next consideration in how to get the job done in a safer or cheaper manner is to determine in what ways the tasks may be altered to accomodate system capabilities.

For some underwater activities there is no clear approach. An example of this is the necessary inspection and maintenance of existing underwater structures and equipment. These have and will continue to produce diver intensive NDT work. Also the general construction support tasks, reviewed in section 3, will continue to require diving assistance/ support, even when they become more advanced, since in some instances only a diver can provide the needed capabilities.

In these latter cases, the short term solution (to provide increased cost effectiveness or safety in operations) is to determine the degree to which the alternate systems do satisfy part of the task requirements, and then to attempt to use the safer/cheaper system to the extent practicable.

Certain factors will continue to make the tasks involved remain just beyond the potential of alternate solutions. For example the problems of turbidity can only be overcome by the ambient diver feeling his way around. In this case any technical solution (i.e. accoustical imaging system) seems to be at least a few years away, and so substitution attempts are currently thwarted. Also some groups contend that having the person at the task itself represents a "human" need which we are satisfying, just as with the space program's manned, only semi-automatic systems. This aspect of the technical solutions will be neglected in the analysis.

With these qualifiers it is possible to examine in general terms what system capabilities exist and to what degree the offshore industry does utilize them.

4.1.1 Determination of Teleoperator Capabilities

In general underwater intervention may be represented by the following steps: First, identification of a needed result, e.g. find out if a structure's nodes are in acceptable condition. This requires some information or data, e.g. the results of NDT. The use of certain equipment is necessary, for example an accoustic probe for ultrasonic NDT. After selecting the equipment to be deployed, the choice of delivery or operator system is made, for example a diver or ROV. This view of the desired product allows examination of the various means for improving the process at any intermediate level. In this case, for nodes, it may be possible to use other ways of monitoring the node/connection conditions (by accoustic monitoring, or other indirect means), or by better NDT methods. Although the concern here is the determination of the delivery system, the other elements are also variable, e.g. the NDT equipment is a likely candidate for expedient improvement.

Presently the offshore industry uses the equipment and techniques discussed in section 3, and the remaining analysis of system capabilities is concerned with the use of established methods and equipment.

Busby has used the following task contents to provide a basis for functional categories of ROV applications:[3]

> Inspection, as opposed to monitoring, consists of determining and documenting the location and/or condition of undersea structures.
> Monitoring, includes observation and/or measurement of tasks which are underway at the time of ROV deployment.
> Survey, involves measurement (i.e. mapping) and sampling of natural and man-made bottom features.
> Diver Assistance, includes tasks in support of diver activities.
> Search/Identification, entails locating and identifying objects intentionally and unintentionally placed on the ocean floor.
> Installation/Retrieval, includes assistance or primary work in installation of fixed structures and pipelines/ cables, and assistance in retrieval of hardware.

Using the above definitions, Busby has reported that for ROVs, the majority of work conducted (for all vehicle applications) is in the inspection/monitoring categories, and that operators estimate that ninety percent or more of the work they are called upon to perform are inspection and monitoring tasks.[4] The means by which these tasks are carried out include use of video, photo and cine equipment, coupled with depth and positioning documentation.

A general consideration of system capabilities identified areas for comparison of system performance of common tasks in support of underwater jobs.[5] Table 4.1 indicates general task abilities. These are not in the context of accompanying tasks; for example cutting and grinding is often preparation for a welding task and would be performed during the same job.

TABLE 4.1

AMBIENT DIVER WORK TASKS

(. indicates types of work performed by offshore ambient divers)

(x indicates types of work which manned and remotely controlled vehicles have also performed)

welding	.	rigging	x
drilling	x	bolting/unbolting	x
cutting	x	assembling	.
grinding	x	grouting	.
inspection (visual)	x	painting	.
measurements (dimensional)	x	site investigation	x
testing (non-destructive)	x	directing surface lifting/ lowering	x

Source: R.F. Busby, "Engineering Aspects of Manned and Remotely Controlled Vehicles". Phil. Trans. R. Soc. London, A.290 (Great Britain 1978) p. 143.

This table indicates that although there are many complex tasks, such as rigging and bolting/unbolting, that either the manned submersible or ROV may accomplish, other tasks such as welding are definitely outside the present capability of diverless systems.

Performance of some tasks by diverless systems may be possible, but with very heavy time penalties or other unacceptable conditions, such as the need to have extensive jig preparations, etc. This discourages use of these means unless no other means are available, such as supporting extremely deep operations.

Manipulative Capabilities

The bulk of the ROVs in offshore use today are equipped only with closed circuit TV capability, with possible photo capability, and a few ROVs have probes for cathodic potential surveys. The actual number of "observation-only" vehicles is approximataly 72 of the 112 non-military vehicles reported in use.[6] Appendix C lists the instrumentation and equipment on the free swimming ROVs. This indicates that of the ROVs manufactured or in use by the offshore (non-military) community, only one, the ORCA, is equipped with a master-slave force feedback manipulator. Other ROVs employ what are basically rudimentary manipulators which limit the tasks they may accomplish to very simple ones. No reports were obtained indicating the use of computer assisted manipulator control (including supervisory control schemes) other than the use of microprosessors for telemetry data processing, for data reduction or transmission needs.

The Navy has reported on the development and testing of more complex underwater work systems utilizing manipulators, but civilian ROV applications are only now beginning to implement advanced manipulative capability, as with the ROV ORCA and the manned ARMS submersible. Without improvements in employed manipulator capability all potential improvements in vehicle utilization will be diminished and be dependent on the ability of the user to re-design tasks to require a minimum of manipulative ability. While this remains the case, the application of ROVs will remain limited, with some light simple manipulative content, and ROV use will not seriously affect the amount of work that must be performed by divers. Manned submersibles of course offer an improvement in performance of tasks when comparted to ROVs with similar manipulative equipment, due to inherent viewing and sensing advangates.

Due to the higher degree of sophistication of potential tasks that are carried out by a manned submersible with manipulator, the manned sub offers potential and actual replacement for the diver in certain circumstances. Problems with this are that sub manipulators do not offer a high degree of capability and may be subject to fairly high costs when compared to the diver. Larger submersibles simply do not have the compactness needed to gain access to many of the tasks, especially for inspection work. Manned subs are not used within a structure's perimeter. Smaller manned subs like the tethered Mantis and Wasp are now available, but their performance is not yet well documented. They may offer some improvements in access, due to their size, but the tethers prevent many types of work related to platforms, especially activities inside the perimeter.

Reflecting the lack of ROV manipulative capability, many operators do not feel that the ROV will reduce the divers task load in areas beyond observation modes. Figures varied, but most persons felt that 90% of the ROV work is and will remain, for the near future, observation-only.[7] This seems to be a pessimistic view, in that there are in-house programs being carried out by some major oil companies that are intended to develop unmanned systems. These are, however, specialized systems, not general work vehicles.

Another area of major uses of ROVs is diving support; identified by Busby and most diving firms, this does not require any improvements in manipulative capabilities and is a real growth potential for ROV use.

Performance Measures

There are no straight-forward measures of overall capabilities outside of laboratory exercises. The following method helps to determine vehicle system capability for offshore jobs that require some degree of manipulation.

Gray and Fike have considered the various modes of access to be a means of delivering the work system or manipulator to the work site. The application of the system depends on the degree of sophistication of both the vehicle and the manipulator. The delivery platform (manned, unmanned) determines the general capabilities because of the limitations of remote navigation, sensing, and maneuverability. Teleoperator configutations have been analyzed by Gray and Fike to provide a way to determine system needs.[8]

First is a consideration of various types of manipulators. The classifications given in Table 4.2 apply to current manipulator designs.

The degree of task complexity or difficulty ranges from observation to sophisticated assembly/dis-assembly. The system capability for the task to be accomplished is given in rough terms in Figure 4.1, Guide to Remote Work Systems Selection. This assumes the other relevant characteristics of the support platform allow the operation, i.e. access, maneuverability, stability, visibility. These supporting elements vary between different vehicles and are not readily quantifiable. They are not always present, especially the four attributes named.

Of the operating manned submersibles today (including the ADSs) few have the "complete rate manipulator" listed in Figure 4.1 (this is with 7 degrees of freedom [DOF]). Vehicle positioning capabilities may be substituted for some of the manipulator's dexterity, allowing more ability with less DOF. This will possibly cause degraded stability and station keeping characteristics. Manpowered manipulator arms are integral to the

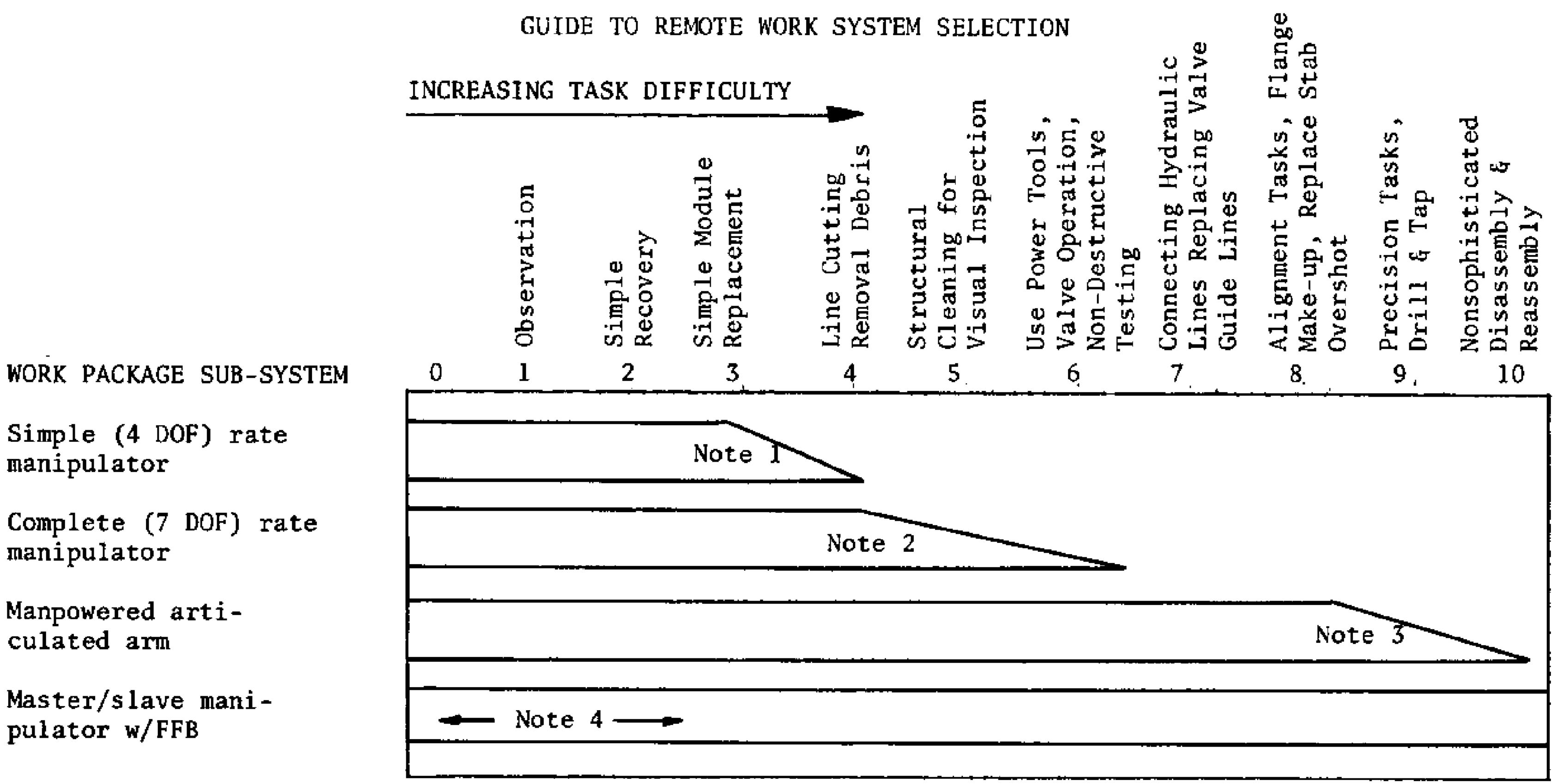
TABLE 4.2 - MANIPULATOR CLASSIFICATION

MANIPULATOR TYPE	EXAMPLE	TYPICAL WORK CAPABILITY	COMMENTS
1. "Through wall" mechanical operators	Early submersibles; ADS manipulator	Simple motions and small clam-shall	Seal dependent, special purpose use only
2. Manpowered articulated arm	Atmospheric Diving Suits	Exploratory drilling support; maintenance of wet trees	Limitation in force & dexterity usually require task adaptation
3. Rate-manipulator-limited motions (3-5 DOF)	Manipulator on SCORPIO remote vehicle	Recovery of small objects; simple module replacement; restraint device	Limited capability, special Purpose applications
4. Rate manipulator-all motions (7 DOF)	Manipulator as used on PC-18 submarine	Debris removal; simple power tool/cleaning tasks	Provides a limited general purpose capability. Operating times are relatively long
5. Master-slave manipulator with force feedback	Manipulator as used on Arms bell or ORCA remote work vehicle	Complex, sophisticated tasks, drill, tap, assemble, disassemble, NDT	Provide a true general purpose capability. Approaches "Diver Equivalency"
6. Special purpose. (Potentially very broad in concept)	Maintenance manipulator for EXXON SPS system or EXXON TMV	Performance of any tasks where development of a "tailor-made" approach can be justified	

Source: Walter E. Gray and J.W. Fike, "Operational Experiences with Remote Manipulator Systems", Proc. 11th Annual Offshore Technology Conference, 1979, p 1960.

FIGURE 4.1

GUIDE TO REMOTE WORK SYSTEM SELECTION



1) Excessive task time. Becomes dependent on vehicle maneuverability.
2) Excessive task time. Becomes 10X that of master/slave.
3) Encounters mobility/reach/visibility limitations
4) Cost may be excessive for simple tasks.

Source: W.E. Gray and J.W. Fike, "Operational Experiences with Remote Manipulator Systems", Proc. 11th Annual Offshore Technology Conference, 1979, p 1961.

JIM and WASP type ADSs. A master-slave manipulator system with force feedback (allowing the operator to sense the amount of force being applied either full scale or a linearly reduced scale) is only available on two or three manned bells and only on one ROV, the ORCA.

In 1978,87% of all submersibles carried a manipulator and 50% of these carried two, such that one may be used for grasping the object of interest or to provide stability for the vehicle. Many of these vehicles are equipped with six DOF manipulators but few of these are with variable rate control on major joints. Most manipulators on the submersibles have so-called bang-off-bang control where the operator may only control the motion of a manipulator by the on-off control of an individual joint's motion. A survey by Busby in 1978 showed that few of the manipulators have any variable rate control incorporated into their controls.[9] Most of these manipulators are controlled by multiple levers, as opposed to single-stick or joystick arrangements. No references were found for vehicle manipulators that utilize resolved-rate-control. This type of system,where computer assistance is used so that control stick motion corresponds to the end effector's required cartesian-coordinates rather than joint-coordinates, is employed to ease operation and increase (timing based) performance.[10] In Figure 4.1 the most simple manipulator configuration has a four DOF capability, and so it may be assumed that most submersibles are grouped within the first two performance lines (4 DOF and 7 DOF), if equipped with manipulators at all.

While ROVs are often equipped with manipulators this is still a minor segment of the vehicle "population". Of 104 vehicles on which information is known, (where this total includes multiples of each model/design), 35 ROVs are equipped with one or two manipulators. Of these there is one operational vehicle with a force feedback control (assumed not master-slave) on the MURS-100, with a maximum operating depth of 100 meters. One vehicle, the MURS-300, under construction in 1979, has master-slave control but apparently without force feedback. The one with a master-slave force feedback control is the ORCA.[11]

Thus relatively few vehicles have manipulation capacity comparable with a diver. This lack of more sophisticated systems states very strongly how capable the ROVs and teleoperators are in general, i.e. not very capable with respect to divers for depths of less than 350 meters.

However, simple manipulators are quite useful. Their effectiveness is by increased tool matching or end effector selection. The most useful manipulators are the ones with dedicated end effectors, such as cable cutters, impact wrenches or grinders. These effectors may or may not be interchangeable below the surface (i.e. remotely). Systems of this type include dedicated tool sets, such as the Navy's Work System Package (WSP). This collection of end effectors is designed to be deployed from the ROVs RUWS and CURV III, or from the ALVIN, SEA CLIFF, or TURTLE manned submersibles. This advanced work system is designed to give the Navy operating capability in depths to 20,000 feet.[12] It includes a tool storage rack with compliant brush-type holders, where tools are kept until needed. The end effectors are automatically coupled to the manipulator. The Navy's RUWS has master-slave force feedback control with an additional rate controlled assisting grab. End effectors may be changed as needed for different tasks. Similar but less extensive systems are employed on some manned submersibles such as the Deep Submergence Work Package (DSWP) installed on submersibles (DSWP is built by Perry Submarine Builders) such as the Perry PC 1801, 1802, and 1804.[13]

Other improvements in capability stem from use of task specific equipment such as coring devices and sampling systems. The task specific tool approach allows for a wide range of capabilities, but not a general task capability. This becomes the basis for task or functionally specific vehicles, on the whole cheaper to develop and maintain, and useful for a small range of specific tasks. A less sophisticated and cheaper manipulative capacity may provide for acceptable performance in its narrow range of jobs.

An indication of the state of the art of the multi-purpose work systems is given in Table 4.3 indicating the relatively advanced tool sets that are employed on the Navy's RUWS system, the Navy's WSP employed on CURV III, and a recently produced commercial system, the RCV-150. Commercial or field evaluations of these systems were not located and their effectiveness is not yet established.

It is apparent that the majority of the civilian vehicles do not have the manipulation capabilities of the Navy vehicles, excepting the ORCA. The manipulators in use are just not sophisticated enough. This will be an area of major developments over the next few years, following the recent increase in vehicle population, if operators realize the potentials. This is currently the case for tailor-made systems, e.g. the EXXON TMV, designed for depths beyond the divers' ranges. Performance improvements will be by use of the known master-slave and force feedback control modes. As shown in Figure 4.1 Gray has indicated a potential time savings accrued by operation times being reduced by a factor of ten, when master-slave capability is introduced. Another source has indicated that the remote operation versus diver task completion times are a function of both the manipulator control method and the special task content, and that

TABLE 4.3

SUMMARY OF THREE WORK SYSTEMS

Operating Mode		Type	Function	Capability
Rotary Hydraulic	WSP	High Speed Low Speed Impact Wrench Reciprocating Knife Chipping Hammer	Brush, Grind, Cut Drill, Thread Bolt-unbolt Cut Synthetic Line Chip	125 in-lb 275 in-lb 1,320 in-lb, to 1-inch bolts 2-in synthetic rope 37 lb, 21 strokes per second
	RUWS	Impact Wrench Abrasive Saw	Bolt-Unbolt,Drill Cut Bars,Wire Rope, Chain	1,800 in-lb,to 7/8-inch hex bolts 70 in-lb,3-inch deep cut
	RCV-150	Abrasive Saw	Cut Wire Rope	50 in-lb,cuts 3/4 inch diameter wire rope in 1 minute
Linear Hydraulic	WSP	Jack Spreader Cable Cutter	Jacking,Tilting Make Openings Cut Wire Rope	19,000 lb,8-1/2 in 2876 lb,13 in spread 23,000 lb,1-in wire rope
	RUWS	Spreader Cable and Chain Cutter	Make Openings Cut Wire Rope, Chain	6000 lb,12 in spread 25,000 lb,1-in wire rope
	RCV-150	Rope Cutter	Cut Synthetic Line	Cuts 3/4-inch diameter synthetic rope

Source: David E. Adkins, D.J. Hackman and K.Collins, "Work Tools for Underwater Vehicles." Proc. 9th Annual Offshore Technology Conference, 1977, p 541.

improvements, in relation to the time it takes to complete a job by the human are not very great even for an expensive manipulator system. As such the master-slave with force feedback will be 2 to 10 times slower than the human hand.[14] Similar data is given in Figure 4.2 for other manipulator control modes. When an operator considers the great costs that are secondary to the primary equipment rates, this helps to clarify why manipulator controls must be improved if there is going to be serious competition with divers. This is especially true in shallow areas, for almost all manipulative tasks.

A summary of system applications and capabilities is shown in Table 4.4, indicating the state of the art for all teleoperator manipulator capabilities.

General System Capabilities

Other general considerations affect the potential use of systems. Many factors combine to make one system more capable than another. An example of this, is the choice of a system for drilling support activities. (Also see section 3.2.1). This is usually the domain of divers but recently the use of a manned submersible, MDUs, and ADSs has been reported. The following paragraphs are quoted to indicate the general capabilities of the competing systems in the context of drilling support and comparing the advantages and disadvantages of three alternate forms of access (versus the diver) - the Pisces class sub, the tethered bells (MDUs), and the ADSs, all of which utilize manipulators.

> The tethered bell system is considered superior to the Pisces in the following areas; from ship personnel for launch and recovery (we believe this difference will be overcome upon the availability of Hyco's launch/recovery system); the availability of live TV provided

TABLE 4.4

MANIPULATION CAPABILITY

(Source: Gray and Fike)

WORK CONDITIONS	Work Conditions	TYPE OF MANIPULATION: Manpowered Articulated Arm	Rate Manipulator Limited Motion	Rate Manipulator Full Motion	Master-Slave Manip.w/Force Feedback
Maximum Depth	250 m.	5	5	5	5
Minimum Force	30 lbs.	3	5	5	5
Force Controllability		3	1	2	5
Minimum Visibility	1/2 m	4	1	1	4
Min. Access Space	30x30 cm	4	1	2	3
Max. Work Radium	1 m	1	5	5	5
TYPICAL TASKS	TASK DIFFICULTY				
Inspect/Observe	E	4	3	3	4
Recover Tools	E	4	2	3	4
Clean, Brush, Chip	E	3	1	2	4
Cut Cables	D	4	1	3	4
Jack, Spread	D	4	1	1	4
Untangle Lines	D	4	1	2	4
Attach Lines	D	3	1	2	4
Connect Hydr. Lines	C	3	1	1	4
Opr. Overrides	C	4	1	2	4
Open/Close Valves	C	4	1	1	4
Stab Overshots	B	4	1	1	4
Make Up Kill Line	B	4	*	*	4
Bolt, Unbolt	B	4	*	*	4
Replace Valves	A	3	*	*	4
Drill, Tap	A	4	*	1	4
Place Shaped Charge	A	3	*	1	4
Precise Alignment	A	3	*	1	4
Non-Destr. Testing	A	3	*	1	4
Replace Modules	A	3	*	1	4
Precise Measurement	A	4	*	*	4

Scoring: Task Difficulty: A=Most Difficult, E=Least Difficult.
System Capability: 5=Most Capable, 1=Least Capable

* Denotes incapability inherent in design.

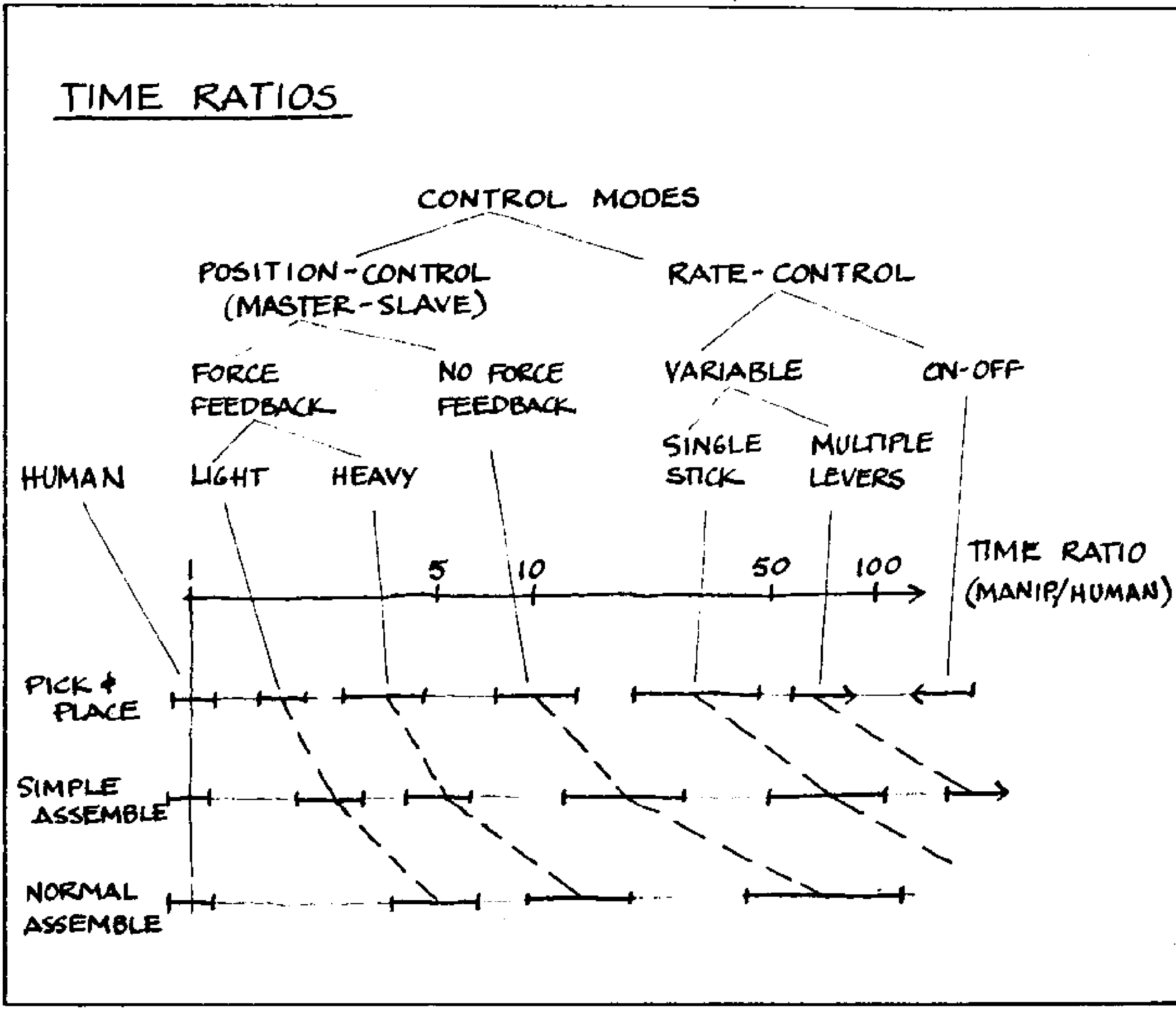


FIGURE 4.2 EFFECTS OF CONTROL MODE ON COMPLETION TIME can be compared on the basis of the ratio of time taken to do the task with manipulator divided by the time taken by a human (Vertut, 1976).

The best are master-slave manipulators with force-feedback which which are 2 to 10 times slower than the human hand depending on the complexity of the task.

Without force-feedback they are from 10 to 50 times slower than the human hand.

Single-stick rate-control (RMRC) is faster than multiple levers, and proportional rate control better than on-off-rate control. Some tasks are simply impossible without the compliance that force-feedback provides.

Source: Sheridan and Verplank, Human and Computer Control of Undersea Teleoperators, (Cambridge 1978).

> to ship's personnel through the umbilical tether; and passenger comfort in the tethered bell which is able to provide a larger interior space to accommodate additional passangers. The PISCES is considered superior over the tethered bell system in the following areas: the absence of an umbilical tether allows the PISCES to maneuver more eccurately for better inspections and re-entry work, free of risk of entanglement, and also permits a free ranging capability allowing it to conduct bottom surveys and retrieval of lost object; its complete independence from the drill-ship eliminates any risk associated with movements of the ship off location. The essential differences between the tethered and untethered systems may be summarized as follows: in accepting the additional tasks which the untethered PISCES is capable of performing and somewhat better inspection and re-entries, drilling personel have to accept video recordings of inspected areas versus live closed circuit television. The often mentioned advantage of unlimited power available via tethered systems has proven to be an irrelevant factor in the type of work performed on drilling operations.[15]

In this case the PISCES VI was used as back-up to the deep drilling remotely controlled television system, and thus was not considered as a full capability system. It was available to assist in any need for conducting emergency salvage of the BOP stack and riser. It is notable that these activities were carried out at depths of up to 4,352 feet, the current record for deepwater drilling, at that time (1978).

Current ROV capabilities are not broad enough to allow ROV support of drilling activities and as such this is not presently considered as a major area of application.

The tasks involved in general construction support are fairly well represented by the activities shown in Tables 4.2, 4.3, and 4.4, and the capabilities of the teleoperators will not be re-examined with respect to construction work specifically.

The primary tasks involved with pipeline tie-ins and welding are generally outside of the vehicle capabilities.

Post installation or production period activities have included the types of tasks listed in the previous tables and are often partially within the capabilities of the ROVs and subs.

A major activity involving the use of ROVs is diver support (with regard to ROVs, although this is really the function of DLO submersibles-additional nearby support for the diver, along with added immediate mobility). This is a utilization consideration rather than a capability, since the primary function of ROVs doing diver support is to provide additional observation capacity.

4.1.2 Utilization Potentials/Reported Applications

This section specifies what means of access or intervention are reported to be used, at all, rather than how much. Little objective data are available on actual use.

We may catalogue the types of tasks reported to have been carried out by various means. This information is shown in Table 4.5. This reported usage shows that although most of the divers' non-observation tasks, such as cleaning, may be carried out by an ROV or manned submersible, few of the working or manipulative tasks have been reported to be carried out by these means. There is a need to qualify this data, however, since this was produced prior to 1979 and may or may not include an accounting of the large number of manipulator equipped ROVs made available during 1978 and 1979. This number is something in the order of 20 new vehicles. Of these at least two, the SMT 1 and 2, are reported to have water jet cleaning capability. The exceptions to the lack of manipulative jobs reported are the instances where a sub or ROV is used to release a pendant or cable, e.g. on a one-way basis, or with the use of specially designed fitting.

Another measure of potential capabilities is provided by a Marine

TABLE 4.5

OPERATIONS AND MEANS OF EXECUTION REPORTED

(x - denotes reported system application)

Operation

CONCRETE GRAVITY STRUCTURES	DIVER	SUB[b]	ROV[c]	FISH[d]
Periodic "green" survey to detect obvious[a] damage and unwanted conditions, e.g.:				
- excessive scouring		x	x	
- debris		x	x	
- large crack & spalling		x	x	
Periodic "blue/red" survey to detect hidden or insipient defects, e.g.:				
- cracks and spalling in local areas	x			
- deterioration of concrete	x			
- corrosion of reinforcement or attachments	x			
- conditions of anodes	x	x	x	
Special surveys of damages, e.g.:				
- impact of dropped objects	x	x	x	
- impact of floating objects	x	x	x	
Remedial measures & repairs, e.g.:				
- sealing of cracks	x			
- casting to cover exposed reinforcement	x			
STEEL JACKETS				
Periodic "green" survey to detect obvious damage and unwanted conditions, e.g.:				
- excessive marine growth	x			
- debris	x			
- scoring or mud build up	x	x	x	
- damaged members	x		x	
- missing anodes	x		x	
- low electrical polarization	x		x	
Periodic "blue/red" survey to detect hidden or insipient defects, e.g.:				
- surface cracks in tubular joints	x			
- corrosion attacks	x			
- condition of anodes	x			

Table 4.5 cont'd

STEEL JACKETS (cont'd)	DIVER	SUB[b]	ROV[c]	FISH[d]
Special survey of damages, e.g.:				
- tight line measurement to check straightness of members	x			
- checking of dents due to impact	x			
- determination of depth of cracks or gouges	x			
Remedial measures and repairs, e.g.:				
- installation of new anodes	x			
- repair welding of cracket joints	x			
- installation of additional strengthening by clamping or welding	x			
- replacement of damaged members by clamping or welding	x			
- restoring or foundation	x			
- removal of debris	x			
- removal of marine growth	x			
RISERS				
Periodic riser survey comprising, e.g.:				
- visual checking of coating to detect cracks and bare areas	x	x	x	
- checking of clamps to detect loose bolts, missing inserts etc.	x			
- checking of clearance between riser and adjacent structures				
- checking of anodes	x	x	x	
- electrical potential measurements	x	x	x	
- measurement of wall thickness and checking of interior surface for pitting corrosion	x			
Special riser survey, e.g.:				
- tightline measurement to check straightness	x			
- close checking of pipe wall or coating damage	x			
- checking of riser displacement monitoring devices	x	x	x	
Remedial measures and repairs, e.g.:				
- renewal of damaged sections by welding	x			
- renewal of pipe wall damage by grinding	x			
- fitting of strengthening sleeves	x			
- removal of anodes	x			
- repairing coating damage	x			
- removal of debris	x	x		
- removal of marine growth	x			

Table 4.5 cont'd

PIPELINES	DIVER	SUB[b]	ROV[c]	FISH[d]
Periodic route survey to detect obvious damage and threats to the line, e.g.:				
- free spans	x	x	x	x
- displacement	x	x	x	x
- insufficient cover	x	x	x	x
- insufficient electrical polarization	x	x	x	x
- damaged/missing weight coating	x	x	x	
- debris	x	x	x	x
Periodic close inspection and monitoring of selected significant areas, e.g.:				
- bare areas for wall thickness and interior wall corrosion	x			
- anodes and earth connections	x	x	x	x
- mechanical couplings	x			
- supports	x			
Special surveys of detected damages or threats, e.g.:				
- mechanical damage to pipe wall (dents, gouges, bends)	x			
Remedial measures & repairs to correct unwanted conditions and damages, e.g.:				
- fitting of new anodes & earth straps	x			
- fitting of strengthening sleeves	x			
- replacement of damaged sections	x			
- placement of covers	x			
- maintenance of mechanical couplings	x			
- restoring of foundation/support	x			
- removal of debris	x	x	x	

Source: H.O. Torsen, R. Sletten, Trends in Underwater Operations with Special Reference to Inspection and Repair of Offshore Installations, Continental Shelf Institute, Norway 1978.

Notes: a. Colour designations refer to Det norske Veritas Inspection classifications.

b. Manned submersible.

c. ROV refers to both free-swimming and bottom crawling tethered systems.

d. Fish includes towed ROVs and also simple towed side scan sonar devices.

Board report on needs relevant to underwater inspection of structures. This summary is given in Table 4.6. It shows that a wide gap exists between the diver and the various teleoperator system capabilities.

TABLE 4.6

SENSORS VS. TRANSPORTERS

TRANSPORTER / SENSOR	SUBMERSIBLES	Tethered		Untethered		STRUCTURAL MOUNT	
	Divers	Manned*	Unmanned	Manned	Unmanned	Permanent	Temporary
Eye	x	x		x			
Television	x	x	x	x		0	0
Camera	x	x	x	x	R		0
Optical Scan	R	R	R	R	R		
Acoustic Scan	x	x	x	x	R		0
Ultrasonic Thickness	x	0	0	0	R		0
Radiographic	x	0	R	0	R		
Magnetic Particle	x	0	R	0	R		
Corrosion Potential	x	x	x	x	R	x	x
Profile Gauge	x	0	R	0	R		
Straight Edge	x	x	0	x	R		
Accelerometer						x	x
Ultrasonic Flaw	x	0	R	0	R		
Platform Tilt and Level Gauge							x
Eddy Current	0						
NOTE: Some sensors require preliminary cleaning:							
(a) Brush	x	0	R	0	R		
(b) Chipper	x	0	R	0	R		
(c) Water Jet	x	0	R	0	R		

SENSOR

x = Existing System
0 = State-of-Art
R = R&D

* Without diver lockout, but includes one atmosphere diving suit.

Source: National Research Council, Committee on Offshore Energy Technology Inspection of Offshore Oil and Gas Platform and Risers.

4.1.3 Capabilities/Application Trends

Based on the previous compilations of system capabilities the systems are defined by their ability to replace or augment the diver. This is especially the case in depths to 350 meters. Beyond this depth serious efforts are made to design different activity needs for underwater intervention, e.g. use of equipment designed to be serviced by limited ability manipulators.

At shallower depths, few of the present divers' tasks may be effectively carried out by manipulators, limiting the application of manned submersibles and ROVs.

Given a similar manipulator control system, the manned submersible will out-perform the ROV during the task completion, although it is penalized by needs to resurface and change crews, charge batteries, etc. Also its support ship needs are more costly. However, manned subs along with the ROVs do not have the overall control, sensing, and manipulative capabilities needed to perform many if not most of the divers non-observation tasks. This is due to the types of manipulator systems that are in use in the field today. These lag behind manipulator systems which have been produced or utilized for conventional land or laboratory work. The cost problems associated with the more complex systems are not documented and as such have not been treated here.

Thus ROV systems currently can perform the following types of tasks-inspection and monitoring, light and/or non-complex manipulative tasks, and diver support. The latter is a fairly "new" area of system application.

Certain vehicle capabilities have not been examined here, such as depth ranges, current ranges, etc. The real constraint on vehicle systems appears to be the manipulative capacity. There are strong trends to produce task specific vehicles, such as the TROV vehicle employed by INTERSUB, which is fitted out with pipeline survey equipment. Vehicles for diver support are fitted out with equipment specified to that use, e.g. hydraulic power supplies, lighting systems, etc.

Identification of a trend toward task specific or functionally specialized vehicle systems is also supported by the conclusions of Busby and the DnV/IKU report, both of which have identified a need for a program to develop, respectively, a diver assist vehicle and an inspection vehicle (structural/NDT).[16,17] The specialization trend semms to apply less for the "eyeball-only" ROVs than for the larger manipulator equipped vehicles, since the choice of capabilities determines the capital cost due to added sub-systems, e.g. manipulators, automatic positioning, automatic ballasting systems, etc.

4.2 System Costs

In addition to the capabilities of a system, the applicability of a certain system is limited by its costs to the user. Other less quantifiable factors also influence system choice. An example of this is the geographical location of a field, with a potential lack of shore logistics support, etc. Another example is the time lag involved in shipping a system to the point of need. This will tend to make an operator cautious and employ a system with well established capabilities.

The costs associated with the use of various systems are a function of the current market situations. These have an effect on the combination of primary and secondary equipment costs. The following sections examine the market influences and cost aspects in turn, and a general discussion of how an operator may choose among competing systems is included.

4.2.1 Market Influences

There are a variety of unquantifiable "market influences" that determine the cost of using various systems. There is an important difference between the real cost of using a vehicle and the price which will be charged by a service company providing it as a service. This is only one of the many factors that complicate the following discussion, which outlines some market considerations, especially on the North Sea markets, but effecting other areas. These have discernable, albeit unquantifiable, effects on system utilization.

The operation of some diving companies has not been clearly competitive. On large projects diving work has been carried out in conjunction with affiliated major contractors, and this has influenced how contractors were chosen. This allowed certain companies to charge non-competitive rates for their contracts. In the past much of the diving support connected with the construction of platforms and pipelines has been carried out from barges and vessels that are owned by the same parent company as the diving service company. This has allowed the offshore manager to specify the needed diving support on a basis that is convenient for requiring the services of a corporately linked company, at the prices specified by that company. It is not fair to single out any particular companies on this, but during the development of North Sea fields, this certainly influenced the costs of saturation diving services.

Most major diving companies provide services to major construction or surface service companies, and as such have been subject to mergers and splits that follow the current general market for offshore services. The service companies include drilling vessel operators and marine construction firms. Oil companies have also had some involvement in the establishment or operation of companies providing underwater services and this again could preclude the awarding of service contracts on a best price or best equipment basis.

These factors tend to retard the introduction of potentially better methods of underwater intervention; money is tied up in systems that must be utilized anyway. Also these factors tend to reduce competition between systems and will stop ventures that would try to introduce a new system.

Price versus cost arguments are important when attempts are made to claim cost effectiveness of systems. A diving system to fill a given need may be obtained for a variety of day rates. An identical system, even from the same service company, may have a range of day rates from $800 per day to $4,500 per day. Price spreads like this are influenced by transient market situations. Currently, in the underwater services industry there are many indicators that point to a market-share fight, which on the near term will hold prices for diving services at artificially low rates.

The results of this will be two-fold. One is that the diver will be utilized on jobs that would normally be within the capability of ROVs. The latter are now in an immature market phase, but being newer systems they are not yet paid for (as much of the saturation diving equipment is today) and so ROVs generally demand day rates more in line with costs incurred. A longer term problem is that the money spent on research and development by the diving firms is dereased, with obvious safety and equipment development considerations.[18]

These factors occur in part due to the end of a big development phase precipitated by North Sea activities over the last eight years. In the wake of the "boom" is a slight "bust", with a decrease in construction projects and a maturing of the markets. This has caused problems for offshore equipment operators and is evident especially in the diving and submersible industries. A major submersible builder and operator, the Vickers Oceanics Ltd. of Leith (VOL) and Vickers Slingsby builders, incurred heavy losses in 1978 due to a price war, and were subsequently reorganized into a joint ownership arrangement with the UK National Enterprise Board, and some private concerns.[19] Another major submersible operator, P&O Subsea also went out of business after incurring heavy losses prior to late 1978.[20]

A similar situation hit major world-wide operating diving firms. Mergers, acquisitions and several other maveuvers have been described as the method by which the survivors are going to make it through the current level of demand for services.[21] The reorganizing of the diving firms is accompanied by some instances of combining more corporate control of the operations, under parent companies, sometimes oil companies, who have their own offshore service needs. This has been the case with one major UK oil company which now owns (in partnership with a Texas based drilling contractor) an offshore underwater services company, combining two previous diving firms and one underwater inspection ROV operator.[22] The important aspect of these considerations is that the current costs associated with the ROV systems may not be competitive. These factors can produce positive and negative effects.

In one case a representative of a diving company stated that they are going to get involved as far as possible with the ROV market. One reason for this interest is to ensure that they are making decisions with regard to substitution. This may imply not using an ROV in some cases, since the company has a better profit margin supplying divers. This has obvious safety implications. At the same time the operator admitted that they will operate their ROVs at a loss if necessary, in order to induce use of company services.

A further market distortion that will tend to make the use of ambient divers available at artificially low prices, is the recent speculation that has taken place in the North Sea area, with diving support vessels. A 1979 analysis of the market for these vessels, most of which are built with integral saturation diving spreads, stated that there were enough diving vessels to provide all of the (at the time 25) North Sea fields with a vessel. It was then predicted that the new vessels coming available during 1979 and 1980 would provide an additional 12 spreads, all with a specialized saturation diving support design.[23] (This does not include vessels designed for air diving support). Based on these expectations the diving system availability will be excessive for the near future on the North Sea, and this will in turn tend to depress diving costs until the blood-letting is over.

The past two years have been hard on diving companies profits, and many are suffering severe dropoffs in business. This does not apply accross the board, but is prevalent. One source indicates this to be not only a sign of a temporary restructuring of offshore priorities, but a sign of a long-term shift in methods of doing jobs formerly done solely by divers.[24] Another company representative stated that they will be reliant on large deeper water platform installations for cash flow during the near future, now that the big pipeline projects have been completed. Major jacket or pipeline projects typically require divers to carry out large programs comprised of tasks beyond the capability of the manned subs or ROVs. In the mean time this company has had to shelve its very capital intensive deep water pipeline construction equipment development program.

When the economics of the diving industry are in a transient phase such as this, the saturation diving system is available at rock-bottom rates, especially for systems which were paid off during the early 1970s and now provide a high rate of return. This must be compared to the generally small profit margins which the ROVs may obtain in today's service market.

In the long run these considerations will not have effects other than delays (or possibly speed-ups) of the introduction of the more advanced systems. They must be acknowledged when trying to establish the rate and reasons behind the degree of utilization of the teleoperators.

Another important change in the offshore underwater operations is the general arrangement for the underwater system deployment. A large primary cost involved with the conventional use of saturation systems has been the mobilization costs for men and equipment, along with set-up costs on the specified user's-provided vessel. This was predominantly on drilling vessels, but for the big construction jobs, such as jackets and pipelines, it involved set-up on construction barges or vessels. In recent years the scale of North Sea fields and their amounts of inspection and maintenance have produced a move towards much more sophisticated permanent configurations for construction equipment. These systems are also appearing on the Gulf of Mexico. In particular this includes vessels with integral saturation support systems, such as the semi-submersible support vessels or Multi-Service Vessels (MSCs) which provide a field or group of fields with long term construction/repair capability. These vessels are offered in competition with another new concept, Rapid Intervention

Vessels,and so typically they will provide firefighting capabilities, construction capabilities, and diving services.

One possible effect on the use of ROVs is that the MSV provide saturation capability by such easy access that the diver is used unnecessarily. Another effect will be on diving safety. MSVs are generally fitted with a saturation system, where provision of divers is sub-contracted. This presents serious safety aspects for the diving company which normally operates, maintains, and sometimes even designs its equipment. One diving company representative expressed some concern with regard to maintaining a safe operation with initially unfamiliar equipment designs with unknown previous performance.

The economics of the ROVs are not subject to these same market changes that the diving industry is going through. Still the diving market has effects on the ROVs' pricing and usage. Most ROVs are operated by diving firms. Due to the extreme financing problems in the diving operations, one company stated that though they have a large ROV fleet, they were not in the market for a major new machine incorporating any sophisticated manipulative capabilities. This was due to cash flow situation that they had expected to last through 1980. So a secondary effect is definitely present.

The economics of operation of ROVs is subject to the usual cyclic influences and pricing problems that face other offshore related markets. Identical vehicles are offered at a variety of rates, reflecting the immaturity of the vehicle market; what one article referred to as the "law of the jungle."[25] By this it referred to the growing host of competing vehicles and operating companies.

In spite of these transient cost and price fluctuations, there are overriding cost savings to be had by use of ROVs in many applications. Primarily these would be cases where the task is well defined and limited to what the vehicle has been proven to be able to carry out. Often the offshore drilling operators state that they will employ a saturation diving capability as an insurance measure, to be sure that adequate support is there when needed. Similar underlying arguments hold for other offshore operations due to potentially high secondary costs.

The various cost elements of the use different systems are reviewed in the following sections along with estimates of the costs of using the various systems.

4.2.2 Operational Costs and Examples

4.2.2.1 Primary Costs, Day Rates, and Capital Expenditures

For specific means of underwater intervention the day rates and ancilliary costs of use are primary costs. Along with these are costs to support the system; the major one is for the support vessel. Depending on the area of use, with the North Sea as an extreme but common case, this may be high in relation to the costs of system use. It appears that the use of most of the manned submersibles, diving spreads, and ROVs, require a vessel of a minimum size, on the order of a small supply boat, to be useful in the North Sea environment. In calmer weather & sea conditions the ROVs would require a smaller vessel.

Other costs associated with an underwater operation are those of secondary operations, such secondary costs are not attributable to the hiring or operating costs of the underwater equipment, but rather are due to production delays, major equipment costs running during underwater critical path activities, etc. These are discussed in section 4.2.2.2.

In order to determine where the teleoperators or ROVs will best produce cost savings, the typical cost elements of an offshore operation must be considered.

For any equipment to be used the contractor of the services will pay fixed cost associated with the minimum use of the equipment. On shorter jobs or one-time basis problems these costs may be very important in the selection of the bids, whether for the same type of systems or not. Often many of the costs of the service are not specified in the daily operating costs, and are "cost plus" to the contractor. Typically these will be for transportation, consumables, and accomodation of personnel.

The following items make up the costs of use of systems whether carried directly by the contractor or figured-in the rates charge by the service company:

Mobilization/Demobilization Charges (mob/demob): These are fixed fees based on the costs that the service company will incur to get a system ready for use and to return it to idle. They will be incurred by needs for maintenance related work or system preparations/check-outs that are made prior to letting the system be taken to the site. Often they will amount to two to three times the equipment or personnel day rate charges and are a lump sum charge. This will also be required for preparation of personnel or procedures for large or difficult jobs.

Set-Up Costs: These are not charged outright but are incurred by the contractor who will be paying dayrates and service costs to have a system set-up and de-bugged on the vessel to be used. These are high for diving services, and negligible for most un-manned systems.

Vessel costs accumulate during this period also.

Transportation costs: These are usually charged to the contractor on a cost plus basis, and apply to equipment and personnel. They are very high for diving systems but are reduced in heavy activity areas. Often the period of transportation of equipment is on day rate.

Working Day Rates and Running Costs: These are the costs which are paid for use of the equipment and personnel on the job itself. They include the rates charged on a daily basis, and hourly surcharges when applicable. In addition to the fixed rates there are sometimes additional costs incurred such as depth pay for divers, ancillary equipment charges (e.g. for a bolt tensioner, etc.) and consumables (fuel, gases, etc.). The contractor is indirectly paying for accomodation of all personnel and other miscellaneous charges, especially when the services are installed on another sub-contractor's vessel.

Tear-Down Costs: These are incurred when the system is no longer needed and include running day rate costs on equipment and the cost to get a system removed.

The above cost elements will not always be critical but sometimes will determine the choice of systems. The working day rates are the most important of these.

Related Cost Factors

A major system will have transit times. A one day transit time is important to consider if the job only requires one working day. Diving systems incur heavy costs for decompression of divers after saturation operations. System operation is limited by weather restrictions; whether diving, manned submersibles, or ROVs; all are limited to launching or retrieval in less than Force 6 to 7 sea states.

Other complicating factors are the stand-by time delays which occur since the use of the underwater system is normally in support of another larger operation. Running costs continue when equipment down-time is encountered, whether the primary equipment or the support vessel. One source commented that for underwater operations "of total time on the fields only 50% is currently used on effective work. The remaining 50% are divided between breakdowns, various delays, and waiting for better weather."[26]

Seasonal fluctuations in work levels affect the determination of dayrates. Offshore equipment is charged for on a basis of amortization funded by employment during less than three quarters of the year. The low overall utilization of equipment is being countered by lengthening of the work season by the increased use of more stable vessels on the North Sea. This has included the successful deployment of diving systems from semi-submersible vessels (sometimes MSVs).

Recent advances have been made in up-grading the surface handling equipment to allow more productive use of divers, including the use of "moon-pools" on many vessels, and cursor bell-launch systems. These allow bell launch and retrieval in more severe weather conditions, providing more bottom time for a given cost, and improve on the competitiveness of the diving systems. Some newer vessels are equipped with dynamic positioning systems. By elemination of the mooring system, a diving support vessel may be relocated in a matter of less than an hour, as opposed to the hours it takes to re-moor an anchored vessel, and the overall productivity of an operation may be improved. A few of the newer bell systems incorporate heave compensators, which will reduce system weather down-time. Heave compensators have also been used by the Navy with larger ROVs, but have not been reported in use for commercial ROV operations.

The above cost considerations will vary from area to area and on the nature of the service being offered. On-going operations such as drilling will require the installation of the equipment on the vessel itself in most cases. Some production platforms have installed dedicated inspection systems, both manned and un-manned. So far this includes the installation of the C.G. Doris (£1 million) system for inspection of the Ekofisk tank. This is an observation/diving bell utilizing a monorail loop around the tank structure's annulus perimeter. It has a locomotive to transport the bell over the desired area to be inspected, and lower it to the depth desired, weather permitting. The tank is in only 60 meters of water and this indicates the efforts needed to provide adequate support services for the inspection needs.[27] One ROV, the SMT-2, is designed for deployment from production platforms. This eliminates the support vessel costs. The specification that allows this is the provision of "intrinsically safe" equipment, required on production platforms (explosion/spark-proof electrical components for the vehicle support system), a feature most ROVs lack.[28]

Other operations require the use of a primary function specific vessel. These activities, like pipelaying or use of other construction support vessels, may require the hiring of an additional vessel to use as diver/ROV support, or the primary vessel may be equipped with saturation equippment. The latter systems generally will not have set-up costs and transportation related costs that accompany the hiring and use of a system from an ongoing operation vessel, e.g. a drilling vessel.

For the different vessel situations there are added restrictions or problems associated with the operations. Accomodation and deck storage areas for diving personnel and equipment are in short supply on a drilling vessel. Gas supplies require large areas for bottle racks and require transport capabilities. Space and transport are obtained at premium costs in some instances and are a factor that makes unmanned, compact intervention systems desirable.

Current Primary Costs

Table 4.7 indicates the estimated range of day rates and costs associated with the different systems. It is based on many sources and conditions and is indicative of costs that would be required to obtain only the primary systems, thus exclusive of support vessel costs. For ROVs the support vessel costs will be from $3,000 to $5,000 per day (plus mob/demob, fuel and consumables, amounting to at least $5 - 10,000 lump sum) for a smaller North Sea vessel; to on the order of $20,000 to $50,000 per day for a vessel capable of supporting a large saturation diving spread.

It must be noted that often the diver or ROV will be able to work in a certain sea state, but that the primary task,such as the winching or lowering of a spool piece may require more calm conditions. Thus all of the equipment will be carried at cost during a waiting period. Similarly most vehicles and divers would be able to work at depth during weather conditions that would not allow launch or retrieval. Operations of the larger vehicles especially are restricted by launch and retrieval condi-

TABLE 4.7

SYSTEM COSTS
(Excluding support vessel, logistics, MOB/DEMOB, and non-heliox consumables)

SYSTEM	APPROXIMATE DAILY COST ($)	ADDITIONAL COSTS DURING USE
Air Diving 8 diver basis	1,500 - 2,000	Vessel
Major Saturation 8 diver basis	30,000 - 60,000	(Included)
Small Saturation Spread 2 diver standby basis	4,000 - 5,000	Gases, depth pay (see text)
MDU	2,700	Use fee $1.00 to $3.00 per ft/excursion
Manned Submersible	8,000	Vessel @ 20,000 to 30,000/ day
DLO Submersible	14,000+	Gases and depth pay
ADS	3,000 - 4,000 (estimated)	Vessel
ROV-Complex Manipulator-Capability	10,000 (estimated)	Possible use charges Vessel
ROV-Simple Manipulator-Capability	3,000 - 4,000 (estimated)	Possible use charges Vessel
ROV-Observation only	1,000 - 3,500	Possible use charges Vessel

tions requirements, with the larger ROVs weighing up to 2 to 3 tons (dry).

Another possible measure of the real cost to carry out underwater operations would be to assess the capital that is tied up in order to perfor the job.

The following paragraphs indicate some of the expenses associated with the systems and include a brief accounting of the capital costs for each basic system.

Air Diving

This is often carried out from the platform itself, especially in the Gulf of Mexico and southern North Sea areas. Capital costs are very low. For depths of less than 50 meters the only large equipment required is a deck decompression chamber, in addition to the divers gear, etc. A small crew is utilized (minimum of 3 or 4 men) including a supervisor. North Sea costs may be from $250 to $350 per man-day, for a short term contract, or from a range of $1,500 to $2,000 per day for an eight man spread. Often this will be limited to daylight work.

Mixed Gas and Saturation Diving

Due to UK and Norwegian regulations all diving to depths in excess of 50 meters require the use of a bell. Although this does not necessarily include saturation diving, the following data applies to full saturation capability. The size of the spread depending on the number of men which must be kept in saturation, thus determining the number and size of the pressure vessels used on deck. Smaller systems are used for drilling support, allowing for two or three men to be kept in saturation when necessary. Larger systems for construction support or those on MSVs may have more than 12 men in saturation at once. The smaller saturation systems have an initial capital cost on the order of $400,000 for a 1,000 foot (capability) system. Larger spreads such as the ones being manufactured today for MSVs cost on the order of $2 1/2 to $3 1/2 million . Additional costs are incurred for an emergency transportable chamber/bell, which may also be used for one-atmosphere observation trips, etc.

The use of mixed gas diving on short deep excursions is termed "bounce diving", and offers an alternative to keeping the divers in saturation. This is usually used (except in the UK and Norway) until the job needs extended bottom time, which then requires maintenance of the divers at bottom pressures between shifts on the bottom.

Saturation or mixed gas diving usually includes the following costs:

- mob/demob, transportation of men, equipment, and gas
- set up, transit times
- compression to job depth
- job time
- decompression period (requires one hour per 6 feet of saturation depth)
- tear-down.

Cost estimates for this work may be considered by a rough estimate or by a detail basis. The cost of a full saturation diving spread <u>including</u> the support vessel, while engaged in a long term contract for inspection of a major North Sea field complex in 430 feet of water, amounted to approximately $6 million (1978 figures). The contract was over an approximate period of six or seven months. This required a 2,000 ton monohull vessel and the daily rate for the overall operation is something on the order of \$30,000 to \$40,000. This did not include any material work, such as modifications or repairs.[29]

A CIRIA report estimates the cost of saturation diving capability, based on an eight man spread, to be around \$40,000 per day, including the vessel. Their estimate is based on a range that goes from \$20,000 to \$60,000/ day.[30]

For a small saturation spread, the costs of a minimally manned system would be as follows (North Sea, 1979 prices):

approximately 10 men at an ave. of \$300/day each	= \$3,000/day
stand-by or long term minimum equip. \$1,000/day	= 1,000
video or other equipment \$400/day	= 400
cost per day,excluding vessel	= \$4,400/day

(A minimum of \$10,000 for mob/demob will be charged, excl. vessel)

This spread would provide underwater access needed for a jackup or semisubmersible drilling rig. When in use, the system will have additional depth pay charges along with gas expenses. One source notes a cost per month of \$110,000 for drill rig diving support.[31]

For a large saturation spread, like the construction support spreads, the costs are much different. The following elements would be applied (for installation on a barge):

Mob/demob	approx. \$10,000 each
Assembly and dismantle	approx. \$10,000 plus day rates for four days
Transit costs to site	at day rates

Day rate for personnel (this would be for a thirty-five men crew which would be required to support a 6 diver in saturation spread, and will provide approx. 22 hours of bottom time per 24 hours period)	approx. $10,000/day
Equipment day rate	$5,000 to $10,000/day
Depth pay (applies to all men in saturation)	approx. $600/man day for a depths of 400 feet, plus $1.20 per foot in excess of 400 ft.
Gas costs	varies depending on whether scavenger systems are used (these are not predominant) approx. $8,000 to $10,000/day

Including the vessel costs, the cost of operation of the saturation spread with 6 men in saturation could be $60,000 to $70,000/day. This could be decreased for long term contracts. It would not include the costs associated with decompression, but would only cover daily gas, personnel, and equipment costs needed for the 22 hours working on the bottom.

Additional equipment that is required for hyperbaric welding would add approx. $5,000/day for a habitat and alignment equipment, and will require the addition of at least two more men in saturation, thus raising the cost of gas, depth pay, and the total personnel day rate.

The cost described above represent a very capable saturation system which could operate as deep as 1,000 feet on a continuous basis if necessary. Examples at the end of this section illustrate the cost to carry out a tie-in with a saturation system such as this.

A vessel that supports a major construction diving spread requires cranage for supplies and equipment, extensive accomodation, deck space for gas racks, helicopter services, and a substantial mooring system, or dynamic positionong. Typical vessels of the latest generation, designed for underwater construction specifically are quite specialized, a requirement for carrying out efficient operations. A vessel like this will offer a manned submersible on option, and possibly an ROV for diving support. (Examples of this are the semisubmersible UNCLE JOHN and the monohull TALISMAN).

One source estimates that 90% of all the cost of a pipeline tie-in is due to vessel costs.[32] This reflects the need for an expensive vessel for this type of work, compared to the support required for inspection work. Also, the use of habitats or heavy equipment sets cranage requirements that often dictate the use of small derrick barges as tie-in support vessels.

A crucial point is that the use of ROVs for diving support in this situation is very cost effective, if say only one day of the job is eliminated due to diver assistance. The higher the vessel cost, the more important this becomes.

Manned Submersibles

A typical manned submersible without diver-lock-out, in use offshore today is the PC-18. This type of vessel now costs approx. $1.4 million for the bare vessel.[33] In addition it will require spares, support systems (such as maintenance equipment on the vessel), and navigation equipment. Most manned submersibles are deployed from a dedicated mother-ship, often owned and operated by the submersible firm. This requires the firm to keep the vessels working for something on the order of 220 days per year at market day rates in order to reach a break-even figure.[34] Other sources cite bare submersible vessel costs in the mid-seventies from $250,000 for a 1,200 foot capability to $1 million for a 3,000 foot capability.

A more recent source quotes the cost of a Vickers LR4 diver lock-out submersible at approx. $1.5 million.[35] This is a Glass Reinforced Plastic hull design (GRP) and the price did not specify included equipment. Diver lock-out submersible systems are operated in conjunction with at least a limited on-deck saturation support system, representing a further investment.

Submersibles have a much more uniform cost/day-rate structure, and rates quoted usually include vessel rates.

During the 1978 North Sea construction season a typical sub with a monohull mother-ship was quoted at a day rate of $28,000. Additional costs will include mob/demob charges, estimated to be one or two days at day rate; and some depth fees and consumables. A similar vessel with two submersibles on board had a day rate of $34,000.[36] Together the two subs would provide 15 hours of dive time per 24 hour period. Another source indicated that day rates in 1977 were somewhere around $8,000 for the manned sub alone, and $40,000 including the vessel[37] This same source indicated that the daily contract cost of a DLO sub would be around $14,000 for the sub, and a total of $40,000/day for the spread. The difference between day rates and contract costs are attributable to the operating costs which the operator pays in addition to the simple day rates.

Other manned submersibles are the Mobile Diving Units (MDUs) such as the Oceaneering International's ARMS. This type of system, built by

Perry Submarine Builders, is basically a partially maneuverable one atmosphere bell fitted with a manipulator. The ARMS manipulator is a General Electric "Diver Equivalent Manipulator" system, providing master-slave force feedback control.

An MDU like this will cost approx. $600,000 for the bell with a regular manipulator. The additional cost of the GE DEM is about $250,000. In addition, the system requires a handling sub-system which will cost approximately $250 K, and spares on board would come to another 8-10% of these costs. This ends up to be about $1.2 million in capital and neglects costs for back-up maintenance and logistics.

A minimum day rate (based on a monthly estimate) for this system without the DEM would be something like $1,000 for the bell and handling system, plus approx. $50,000 for necessary personnel over one month (or $1,700/day). Also there is a usage fee of $1.00 to $3.00 per foot of depth (up to 2,000 feet) apparently on a per-excursion basis.[38] There would be mob/demob, transport, and set-up costs, etc., which could easily be more than $10,000 per job.

A similar system to the ARMS is the COMEX MOB deep diving bell, offering similar capabilities.

A third type of manned submersible is the ADSs. These are essentially small tethered submersibles. There are a variety of competing designs. Little cost information is available.

A future design to be available from ISE Ltd., is the Wrangler. This is offered as a simple system, cost will be approx. $310,000. The costs are attributable to the following:

Basic vehicle	$260,000
Insurance	5,000
Sea Trials	30,000
ABS Certification	15,000
Total	$310,000

The system requires surface support and a handling system. Other similar vehicles such as the SPIDER, a GRP design, have been reported to cost around $300,000 each (stripped).

Day rates were not obtained for these vehicles. One source quoted the cost of a small three day operation (one day for set-up, one day for work, and one day for demob). The total job cost was indicated to be $50,000.[39] These costs were for a JIM type suit, a design primarily used for drilling support. Another source states that the cost of using the JIM for drill rig support would be less than the cost of a saturation spread, which would cost approx. $110,000 per month.[40] This source also stated that the ADS diving support for drilling rigs becomes more cost effective than ambient diving in water depths greater than 150 meters. This represents the depth which (in non-UK or Norwegian areas) bounce diving is usually limited to, and implies the ADS is more cost effective than when the mixed gas system must be used on a saturation basis, even if for a short job. Actual costs of the ADS systems include those modifications to primary equipment needed to utilize the ADS, such as staging, etc., for the JIM and SAM types. Other costs include mob/demob, transport, personnel, and consumables, all of which are minimal. It is not noted in the literature, but it appears that these units usually are used in conjuction with a back-up or duplicate ADS on board; however, detailed cost information was not obtained.

Remotely Operated Vehicle Systems

Cost data was not obtained for towed or bottom crawling systems. There are various costs associated with the different ROVs. Unless the job for which these costs are estimated is totally within the capability of the ROV, the ROV is a diver assist vehicle (in a practical sense) and the cost of the diving system should be considered as the true system cost, with the ROV considered as part of the spread. In this case the ROV does not provide a replacement system, but increases the cost effectiveness of the diving system.

Capital cost of an ROV is a function of the degree of sophistication of its sub-systems. This is discussed further in section 7 of this report. The systems available today are divided into the observation-only type camera platforms vs. the more sophisticated types of manipulator equipped vehicles. The latter are considered on a scale of how well they are equipped, which determines the capital costs and day rates.

ROVs in general require an investment in the vehicle and its support and control systems, along with a certain amount of on-site spares and general (on-shore) spares. The ROVs appear to require more spares than competing systems, with more than one source indicating that the cost of a necessary inventory of spares is something on the order of 20% of the system cost.[41] This seems to be true for more than one manufacturer and is a high percentage. For some of the larger vehicles, operated in remote areas with no nearby similar systems or equipment, this could amount to over $100,000 for a vehicle with only limited capabilities. The cause of this expense is reported to be the high cost of the low production runs of the ROV vehicle components, a problem which keeps vehicle costs high.

Among the different vehicle manufacturers the costs differ even for very similar systems. What has happened is that some manufacturers produce a high quality, expensive product while others are aiming for the less costly system market. This has produced two cost levels with some reflection of this in the day rates. Also this may be explained somewhat by the fact that the more costly vehicles, such as the SCARAB or the RCV-150, are built by companies that also deal with major military vehicle systems or provide sub-systems and components for military (Navy) use. As such they may have product cost structures, based on cost plus contracting, which are generally high. These vehicles are built to higher quality specifications since they do incorporate some military specification sub-systems. This allows the manufacturer to produce a higher reliability product. This is a major differentiation between systems in the current stage of ROV development.

The following data is given to provide estimate of how **much** the ROV systems cost. It does not necessarily reflect the present actual cost of vehicles or systems. It is not offered as representing the manufacturers quoted prices, but is based on estimates (in most cases) by persons involved with the ROV industry. Also the exact basis of the quote has not always been exactly stated, and the inclusion of handling systems (if used) or similar equipment if not always known unless stated.

A very well equipped system such as the ORCA appears to have a price tag of approx. $1.5 to $2 million. However, this is not a production vehicle, and as such would have been built on a very costly, one of a kind, basis. Still even if more than one were produced (not the case in fact), there would not be vast cost savings on production of only a few of these vehicles. Actual day rates for this vehicle were not obtained. They are estimated to be around $10,000 /day (to commercial customers) exclusive of support vessel. Real costs must include shore support and logistics for major vehicle systems, but are not estimated.

A recent report on the ROV systems estimated the cost of sophisticated ROVs such as the ORCA, to be in the range of $1 to $2 million during 1978. It also stated that for a well equipped inspection orientated vehicle (assumed to have the manipulative capacity for NDT inspections) the anticipated future price would be on the order of $2 1/2 to $4 million.[42] The associated day rate for a vehicle like this (to amortize over a five year period, with a simple 10% cost of capital), would have to be high. At least $65,000 per month would have to be cleared on operations for amortization costs alone in addition to any running costs, etc. This indicates a daily operating cost of $10,000.

A less expensive, but sophisticated ROV is the AMETEK-STRAZA SCARAB. The cost of this system has been estimated at $1.3 million.

A less capable, well equipped system is the CETUS. Prices for this system were not obtained, but one source indicates that the basic system is available on a long term contract basis for approx. $4,000/day, excluding vessel costs.

The SCORPIO system, offering manipulative capacity is available for roughly $440,000 for the basic vehicle system. This includes a 3,500' tether cable, 2 operator control units, and one winch. It also includes standard items: CCTV, CTFM sonar, a 5-DOF manipulator, and automatic depth and heading control systems.

Another fairly expensive system with manipulative capability is the RCV-150 system. A source (other than the manufacturers of the vehicle) stated that it would cost at least $500,000 for the basic system. They stated that when they would have completed all the necessary ancilliary systems, such as personnel, shore support capabilities, etc., (including the de-bugging that accompanies the introduction of all underwater systems) they would have an investment on the order of $1,000,000 tied up in the system.

The TROV series produced by ISE Ltd. is a highly capable system. It sells for as low as $450,000 for the full spread. This is assumed to be inclusive of an adequate accountic navigation/positioning system, but is not a price quoted by ISE. It is designed to be a less expensive system. It has two manipulators. Due to its relatively low price this vehicle is a production orientated system and a large number of vehicles have been sold. Each vehicle may incorporate customer-specific sub-system requirements, so costs vary within the TROV "family" of vehicles.

Less capable systems sell for correspondingly lower prices. In the "observation-only" category of ROVs costs also differ. Probably the most expensive (in terms of initial cost only - since true operating costs were not obtained) is the RCV-225 system. It is a commercial model-adaptation of the TORTUGA vehicle developed for the Navy, combining the automatic control system technology that was developed for the Navy's ANTHRO vehicle system.[43] The RCV-225 costs on the order of $220,000 for a vehicle (without a launcher/garage) with spares etc. It is small enough (180 lbs dry weight) that a minimal handling system may be adequate for some applications. This cost includes a control system, monitor, etc., and would be a minimum system. The RCV-225 system including the launcher/clump, used for umbilical control around structures, etc., costs approx. $440,000.

Other "eyeball only" systems such as the TELESUB, RECON III, or the TREC cost approx. $150,000 for the basic system, and are very similar in capabilities. These represent the medium priced observation systems, and sometimes they are fitted with c-p survey probes, but are very limited in non-observation capability. The TREC system does include a 1 to 3 function manipulator allowing some additional capabilities. Some include cable/tether cutting mechanisms for emergency use, but otherwise are in fact highly maneuverable instrument/CCTV platforms.

At the lower price ringe of the remote viewing systems are the newer minimum price/minimum capability systems. Included in this category are the most recent additions to the ROV market, vehicles like the SMARTIE, FILIPPO, DART, SEA SPY, and UTAS. The primary functions of these vehicles is to provide a highly mobile CCTV system. The value of this during underwater operations must be realized since they typically employ high sensitivity video cameras with viewing capability in excess (range) of a human eye. Some of them may be fitted with c-p probes, but generally they are very small vehicles, with limited maneuvering or automatic control capability, and capable of access to tight/small situations. They cost around $50 to $100,000 and usually do not include any navigation system. They are offered in direct competition to the RCV-225 class of vehicles.

The day rates charged for ROVs are generally in line with the vehicle cost and abilities. For the vehicles that are less sophisticated, prices range as low as $1,000 to $1,300/day, and as the vehicle gets more expensive, like the RCV-225 (which offers high reliability and control quality) the price reflects this. These vehicles cost on the order of $3,000 to $3,500/day, inclusive of the three man crew of operators and a supervisor, generally providing a continuous 24 hour per day operation. Hourly rates during use may also be added to the basic day rate.

Generally, the ROV systems require very little set-up effort. They are normally transported and operated from self contained containers or vans. Additional cost to the contractor will include transportation, installation, and a mob/demob on the order of a few days of day rate.

The total cost the vehicle operation translates to is dependent on the area of use and the actual use. The minimum vessel size for any North Sea operations requires something like $5,000 to $10,000 in mob/demob, along with the $2,000 to $3,000 minimum day rate for a small vessel. The total cost to operate the system on a vessel hired to be used only for the ROV system will easily climb to approx. $6,000 or more a day. This will only provide CCTV or c-p information. Data from a survey among contractors found that the actual costs charged during 1977 for ROVs in general was around $5,000/day, for operations <u>without</u> support ships north of 56°N. With the inclusion of the support vessel, a <u>contract rate</u> would be up to approx. $22,000/day, assumed to include all costs to the contractor. This is representative of realistic costs for ROV services in that area.[44]

Comparisons - Primary Costs

When systems are used for a similar task, the cost for the task is comparable and may provide some relative productivity information. This was done by CIRIA for an estimation of future markets for underwater services in the area of structure inspections. Because its primary intention was not to provide a system performance comparison, but rather an overall market estimate, it should be viewed as only a rough approximation. This data is given in Table 4.8. This shows a very good productivity rate for the ROVs with lower range rates, but these must be contrasted with the high range ROV rates which produce a lower productivity (higher cost per unit output)

TABLE 4.8 PRODUCTIVITY CHARACTERISTICS OF THE VARIOUS MODES OF ACCESS FOR UNDERWATER INSPECTION IN 1977

PARAMETERS OF THE SPREAD	UNITS	OPERATIONS N 56°N			
		Saturation diving	Manned subs	Manned sub with DLO	ROV
Output of the spread					
Number of dives per day	number	6	2	2	1
Number of working divers per dive	number	1	-	1	-
Typical duration of work per dive	hours	3	4	4	14
∴ work output by the spread per day's work	man or machine hrs.	18	8	8	14
Operational stoppages					
Annual weather window	days	150	180	180	210
Bad weather stoppage within the window	%	30	25	25	20
Restrictions on access to work site	%	20	5	5	20
∴ approx. operational proportion of the window	%	50	70	70	60
Cost functions of the spread					
Assumed daily hire cost of contract	$ $	40,000 (a) 20,000 (b)	40,000 (a) 15,000 (b)	40,000 (a) 34,000 (b)	22,000 (a) 9,000 (b)
∴ cost per operational day (with ship)	$ $	80,000 (a) 40,000 (b)	57,142 (a) 21,428 (b)	57,142 (a) 48,570 (b)	36,666 (a) 15,000 (b)
∴ cost per unit of output	$ per man or machine hr.	4,440 (a) 2,220 (b)	7,140 (a) 2,680 (b)	7,142 (a) 6,070 (b)	2,620 (a) 1,070 (b)

Notes: (a) Costed on the basis of actual daily rates in 1977. (Average cost).
(b) Costed on the basis of "ideal" operating conditions. (Lower limit of range).

Source: CIRIA UR-13, p 42.

than the lower range of saturation diving costs. This was based on 1977 prices. Currently many firms offer saturation diving equipment at rates equal to or less than the rates charged in 1977. Whether ROV rates are as stable is more difficult to ascertain, as was discussed in section 4.2.1. The effect may be a temporary cost advantage for saturation diving systems even for relatively simple work, such as inspection tasks.

An example of the kind of cost involved with a major underwater offshore job is given in Figure 4.3. This graph indicates the costs (on a total incurred basis) of performing a pipeline tie-in by both a mechanical (non-welding method) and by use of a hyperbaric welding spread. The calculations and the make up of the hypothetical (but typical) job are given in Appendix F. This included a transit time, stand-by time, and similar costs that are realistic for a North Sea large diameter pipeline tie-in with a single connection to be made. The most important aspects of the results are the heavy costs incurred due to decompression times, which increase with the deeper work. The cost incurred after the job completion time (marked on Figure 4.3) is a function of decompression times. The percentage of the total cost due to decompression needs is a function of job time and saturation storage depth. For the case examined decompression required costs are approx. 25 to 42% of the overall costs (for 400 foot and 1,100 foot respectively).

Figure 4.4 indicates the relative cost elements of the operations, by giving the costs of only the vessel (suited for an operation of this type). For the deeper water operations the support vessel costs are a smaller proportion of the overall cost of the operation. The majority of operations of this type have been carried out at depths of less than 450 feet, and the vessel costs play a large part in the decisions concerning costs. For this reason the use of ROVs has found a large potential market in

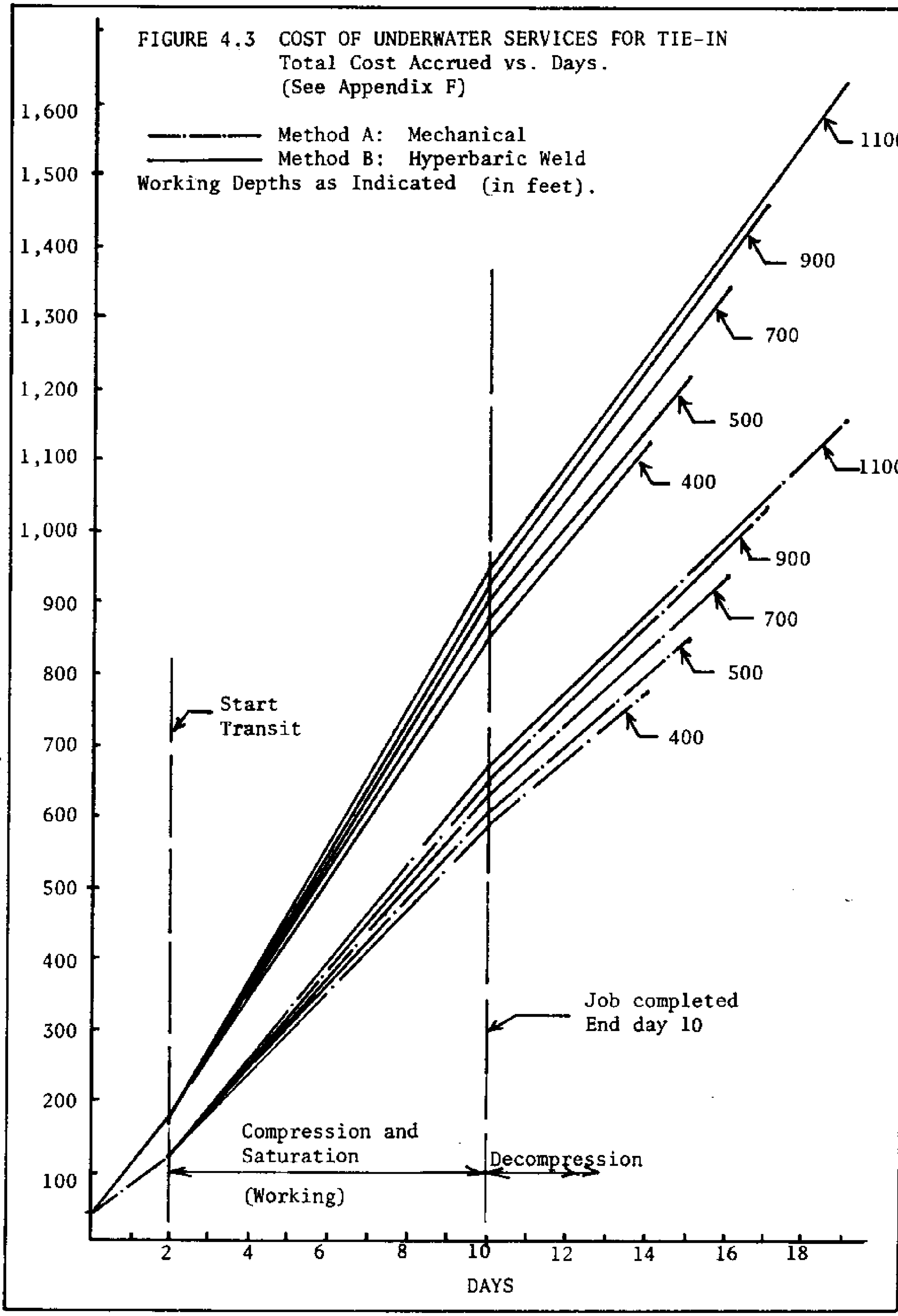
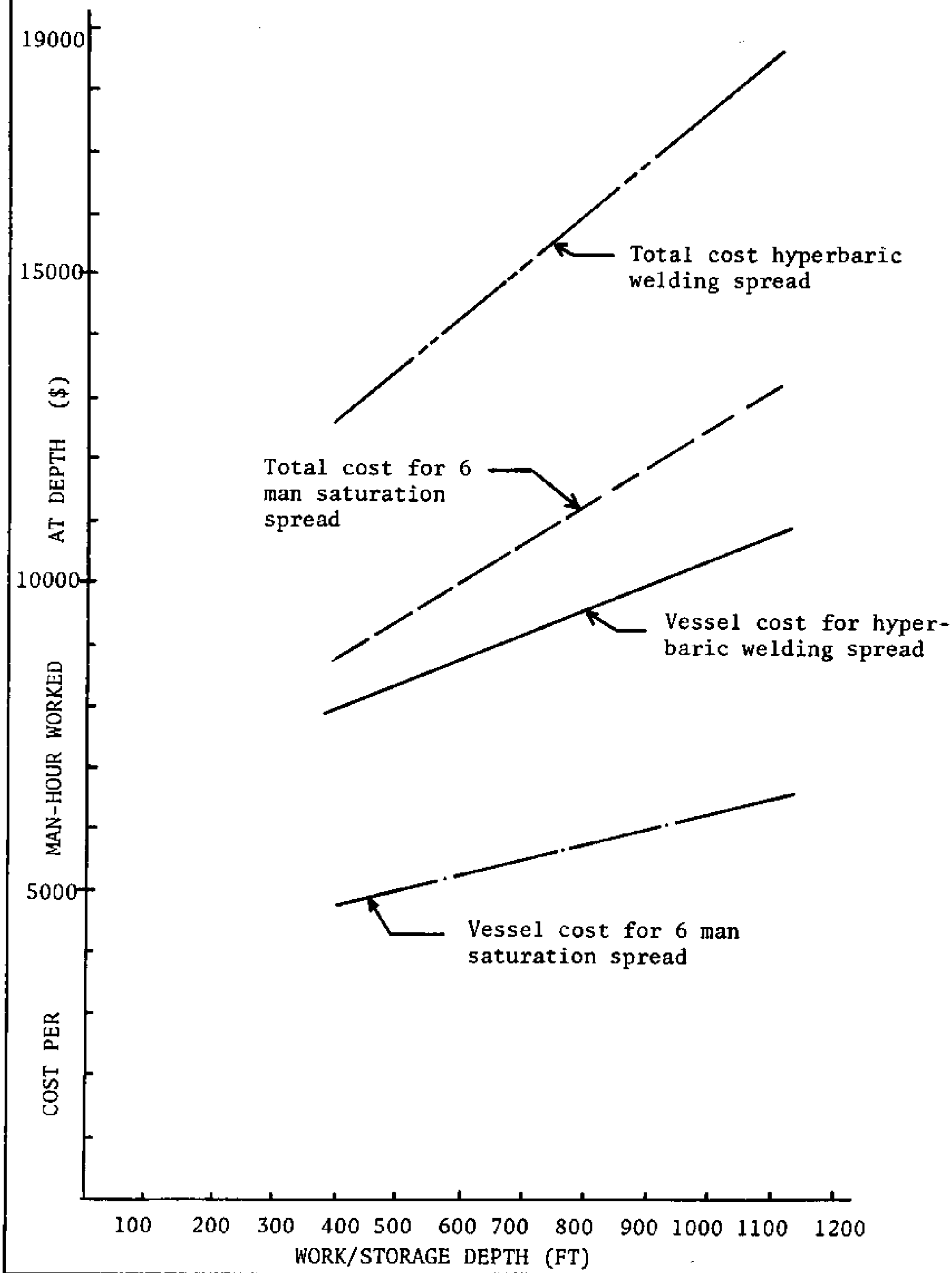


FIGURE 4.3 COST OF UNDERWATER SERVICES FOR TIE-IN
Total Cost Accrued vs. Days.
(See Appendix F)
Method A: Mechanical
Method B: Hyperbaric Weld
Working Depths as Indicated (in feet).
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
ACCRUED COST IN $1,000.
1100
900
700
500
400
1100
900
700
500
400
Start
Transit
Job completed
End day 10
Compression and
Saturation
(Working)
Decompression
2
4
6
8
10
12
14
16
18
DAYS

FIGURE 4.4 TOTAL COST PER MAN-HOUR VS DEPTH
(With 50% downtime and delays and 22 hrs working/day)

(See Appendix F)



diver assistance, where the ROV is used as an observation vehicle only, but may save a half day at a time by providing good bottom reconaissance, or similar services. This may provide savings to the project in excess of the marginal cost of using the ROV.

4.2.2.2 Secondary Costs

Secondary costs associated with the critical path activities of the underwater operations may override the primary cost considerations. For these reasons ambient divers have and will continue to be deployed in situations where a ROV or manned submersible could be used. This has a safety issue connotation since every dive not made provides for less risk to human life. Still, very high losses sustained during periods of curtailed or suspended field production, due to,say, the replacement of a riser or other remedial efforts, will outweigh any consideration of use of a system with a potential for not being adequate for the task.

Dynamically positioned drillships cost something on the order of $100,000/day for the drilling vessel and services. This does not cover the total cost of the drilling operation, which would include transport vessels, shore support, etc.; costs carried for every day of the drilling programs' duration. Systems like this operate in deeper waters, and if not beyond the range of divers, will use divers when possible as support.

Conventional lay barges are operated on contract rates in excess of $100,000 per day and as such need adequate underwater services which only the diver based system may now provide by itself.

This aspect of the cost of system usage will continue to be a restriction of ROV usage regardless of the safety of certain activities, until the operator is either required to find new ways of doing tasks, or cost of diving becomes prohibitive.

In the early projects on the North Sea the contracts were usually let on a cost plus basis and as such spread the risk of incurring a bad weather period among the service company and the contractor, since the contractor picked up any costs during weather down-time. In the past three years there have been a number of very specially designed lifting and pipelaying vessels brought into use on the North Sea. This has led to lump-sum contracts for offshore services along with a maturing of the markets for these vessels. This provides a further impetus for a contractor to provide the maximum capability necessary for underwater intervention, since any extra time spent on lump-sum contracts will jeopardize a service contractor's profit margin. This contributes to an increased use of diver systems for borderline needs (on a purely technical ability basis) when potential ROV system capabilities are considered.

4.2.2.3 Operational Planning

The use of a system requires applicability. For cost effectiveness the operations may be divided into portions that are within the range of the ROV system capabilities, while remaining portions of the job require divers. This has allowed the use of vehicles in a diver assist role, reported offshore users to include the following tasks:

- reconaissance and location of work site, providing assistance to location of support vessel prior to lowering diving bell or equipment.[45]
- monitoring of diver for the diver's initial gear check out, and monitoring of diver during tasks, for both safety and job perfor-

mance. Also this allows surface assistance and directions.

- evaluation and inspection of divers worksite for safety reasons
- documentation of divers work, while in progress, rather than by diver with hand held video after the operation.

These attributes of the ROV assistance are being utilized increasingly.

For more difficult to implement ROV usage the capabilities of potential system usage, say for manipulation tasks is not as easily defined.

The most important consideration is that the risks of an operation are most effectively reduced when a diver is not used, and even when assisted by an ROV the risks are attendant. So the use of an ROV does not always provide an increase in the safety of an operation, unless it is imployed as far as possible without divers.

As ROV usage becomes more widespread the operators may well find them more capable than believed at the onset of availability. In this way the role of ROVs is dependent on the industry efforts at utilization.

4.2.2.4 Summary - System Costs

The use of ROVs may reduce costs by providing a replacement for the ambient diver, or by providing assistance to the diver which makes the diving operation more cost effective.

Current market influences on diving costs are producing a transient low cost for diving services. One of the results of this condition will be an increased motivation for diving companies to provide broader services (such as ROV support), to increase the cost effectiveness of the operations (by use of more stable vessels, heave-motion compensation systems, and other diving system attributes), and by an increased use of ROVs in a support role. The immaturity of the diving and ROV markets will make it difficult to predict actual savings from possible use of ROVs instead of divers. The majority of work is carried out at depths of less than 200 meters, and in this depth range ROVs provide considerable savings for simple tasks. In deeper ranges the use of ROVs or MDUs, ADS, and manned submersible, (other forms of teleoperators) provides savings, but with limited capabilities.

4.2.3 Choosing Systems

Due to the variety of offshore underwater tasks, certain types of work require systems that have well established capabilities. Still there is a latitude in system choice due to the variety of vehicles available. The better planned an operation, the more choice the operator will have in system needs.

The potential for use of an ROV system will be a function of the following factors:

Criticality of the job (e.g. loss of production situations)

Length of the job (e.g. is it long enough to use a variety of systems at different stages?)

Difficulty of the job

Continuity of the job (does the underwater activity get low priority access and need to make the best of it, or have longer uninterrupted work periods)

Risk/safety of the job (e.g. use of explosives or access in dangerous areas, like inside submerged vessels, etc.)

Certainty of the job (inspection type work or stop-gap repair measures).

Given the above variables no certain system is best unless the job is known.

Part of the cost determinants for use of alternate systems are the regulations applying to the use of bells and saturation diving techniques. The prohibition of bounce diving and live-boating varies from country to country. Also the depth limits for certain equipment vary. These impose costs for depth ranges for ambient divers, which will determine the depth at which the manned submersible or ROV will become cost competitive. Other factors will determine the support vessel requirements, which may determine the marginal cost of the support of a saturation spread, (e.g. for pipelaying operations the costs of support vessel is determined, and so the cost due to the need for a support function for 80 tons of saturation system is not considered).

These factors all work together to determine the best system.

4.3 Utilization of Systems

There is very little data available on the use of the alternate modes of underwater intervention and access for any user sectors, including the offshore oil and gas industry. The data given in Table 4.9 is indicative of the support functions for which the different systems are applied. It is based on rough estimates derived from the reported use of systems in trade journals and will be discussed in more detail in the following sections.

The lack of good use data and the continually evolving use patterns preclude determination of actual percentage figures for the employment of

TABLE 4.9

SYSTEM UTILIZATION - APPLICATIONS

SYSTEM	General Surveys (Routes, field)	Drilling Support	CONSTRUCTION SUPPORT Pipelines	CONSTRUCTION SUPPORT Platforms	Inspection	Repairs-Jackets	Repairs-Pipelines	Diving Support/Assist
Surface-Supplied Diver (Air and Mixed Gas)	NA	I	I	I	I	I	I	NA
Saturation Diver	O	I	I	I	I	I	I	NA
Atmospheric Diving Suit (ADS)	O	I	NA	NA	O	NA	NA	NA
Mobile Diving Unit (MDU)	NA	I	O	O	O	O	O	NA
Manned Submersible	I	NA	O	I	O	NA	NA	NA
Submersible with Diver Lock Out (DLO)	NA	NA	I	I	I	I	I	NA
Remotely Operated Vehicle (ROV)	I	NA	O	I	I	I	I	I

I - Major Application/Use
O - Minor Application/Use
NA - Not Applicable or Neglible Volume of Use

the different systems. Instead the following sections review the approximate data available for each system. This gives an idea of what the relative amounts of each system's uses are in support of. This is done in the following section for ROVs, diving systems, and the manned submersibles. Following this, the roles of these systems are examined in the context of underwater inspection of structures and pipelines. Estimates of the future division of this inspection market between these systems are reviewed.

4.3.1 ROVs

Table 4.10 indicates the owner/operator orientations for the existing ROVs (including only the tethered free-swimming vehicles). Data from Table 4.10 is graphed in Figure 4.5, which illustrates the rapid growth of the ROV "population" over the period 1976 to 1979. In 1977 there were a total of 32 ROVs used world-wide in support of oil and gas operations; by 1979 this grew to a total of 102 vehicles. Most of these are "eyeball only" systems. Still the number of vehicles with manipulative capacity was at least 13 in 1977 and rose to 32 available in 1979, a large increase even if not at as rapid a growth rate as the non-manipulative systems. This substantiates the large percentage of the jobs that these vehicles carry out in the general areas of inspection and monitoring, as discussed in section 4.1.1. Table 4.9 indicates work for survey of pipeline routes and annual or regular pipeline surveys. Present ROV systems perform this task well and this is an often reported utilization area. Jacket and pipeline repair by ROVs really refers to the reconaissance and assessment operations that are carried out with this type of work. Damage assessment is a valuable function of these systems since the ROV may make vertical excursions without difficulty, to determine the path and damage of fallen equipment or objects, a capability that is not possible with divers for deeper jobs. Diving assistance is a major area of usage and was discussed in previous sections. This may be one of the largest areas of ROV application.

4.3.2 Divers

Table 3.4 lists the revenue sources for a major North Sea diving contractor. This is assumed to be fairly representative for overall North

TABLE 4.10 OWNER/OPERATOR ORIENTATIONS OF FREE-SWIMMING TETHERED ROVs[a,b]

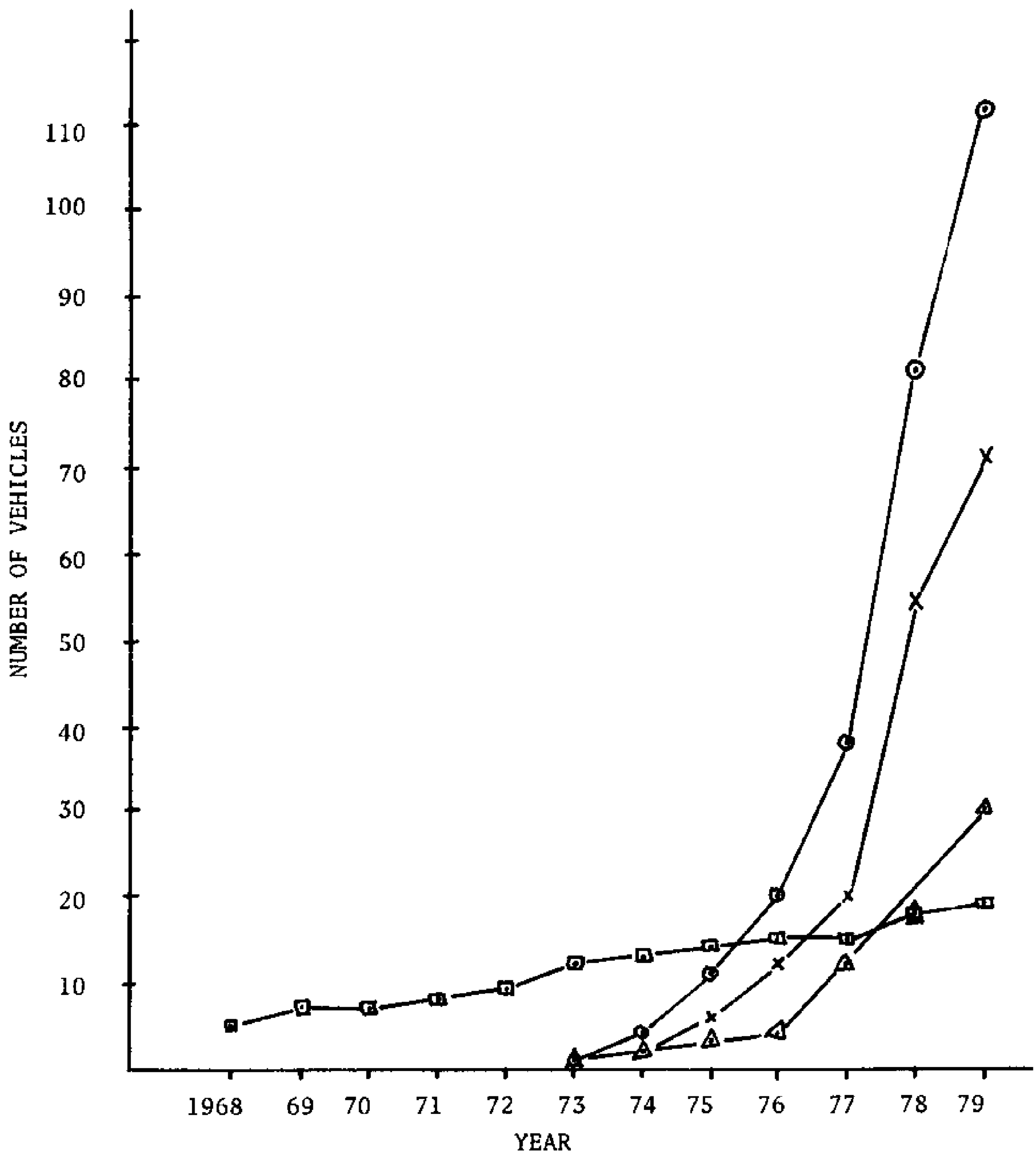
YEAR	Total Vehicles (Active+Inactive)			New Vehicles		Active (Non-Military) Vehicles					
							Supporting Oil and Gas Operations			Other Uses	
	All Users	Military Users	Non-Military Users	Military	Non-Military	Total	Total	Total obs. only	Total w/ Manipul.	Total	Total obs. only
1968	5	5	-	5	-	-	-	-	-	-	-
1969	8	7	1	2	1	-	-	-	-	-	-
1971	10	8	2	1	1	-	-	-	-	-	-
1972	11	9	2	1	0	-	-	-	-	-	-
1973	15	12	3	3	1	1	1	-	1	-	-
1974	20	13	7	1	4	4	4	2	2	-	-
1975	28	14	14	1	7	11	9	6	3	2	-
1976	39	15	24	1	10	20	16	12	4	4	1
1977	57	15	42	0	18	38	32	20	12	6	1
1978	106	18	88	3	46	82	73	55	18	9	2
1979	140	19	121	1	33	112	102	72	30	10	2

(a) excludes NATO mine-neutralization vehicles.
(b) based on data in "R.F. Busby, Remotely Operated Vehicles, pp 18-23.

FIGURE 4.5 ROV "POPULATION" (BY OWNER/OPERATOR AND CAPABILITIES) VS YEAR

(Based on Table 4.10)

Key: —□— Military
—⊙— Active non-military
—△— Offshore oil and gas support (with manipulator)
—x— Offshore oil and gas support (observation only)



Sea underwater activities and thus diver employment. CIRIA UR-13 indicates that approximately 20,000 man days of diver effort were contracted for all inspection efforts alone, in all North Sea areas, during 1977. With a weather window of 150 days per year (and requiring each company to employ two to three divers for each working diver crew member - possibly a high estimate) this requires approximately 350 divers for all North Sea inspection needs only.[46]

Table 4.11 indicates the composition of the diving crews that would be needed for the inspection work, based on the apparatus used and the necessary training (e.g. not abilities).

TABLE 4.11

1977/78 REQUIREMENTS FOR NORTH SEA UNDERWATER INSPECTION

<u>Qualified Inspection Divers*</u>	
Air Diving	75
Saturation Diving	55
<u>Other Divers</u>	
Air Diving	155
Saturation Diving	65

* qualifications not specific, but indicate trained for structural inspection.

Source: CIRIA, The Market for Underwater Inspection of Offshore Installations in the Next Ten Years - Report UR-13, Atkins Planning, CIRIA Underwater Engineering Group, (London 1979) p 38.

An estimate of 350 divers corresponds to approximately 17 to 18% of the 2,000 divers who are estimated to be employed on the North Sea for all types of diving in all areas. This seems to substantiate the revenue distribution given in Table 3.4, which indicated that 20% of all the diving is carried out (presently) in support of all insepetion work, not directly associated with the actual construction or repairs. Other information on the utilization of divers is contained in Table 4.12, which indicates the type of services offered by various companies operating in the North Sea market. The total number of divers listed is apporximately 2,000, which agrees with other sources. These are North Sea divers, out of a total world wide commercial diving population of at least 4,500 or so divers. These figures include commercial air diving for many areas, and as such are not representative for saturation capability for either personnel or equipment.

Data on the US diving population has been compiled by the NOAA M.U.S.T. project.[47] Further information was received from a representative of a major US firm.

Based on these two sources there are an estimated 2,000 full time employed US commercial divers today (while there were approx. 1,530 in 1975). Of these approx. 1,000 are employed in support of oil and gas operations. Of this group approximately 200 or 20% are primarily employed in saturation diving. Many of the total 2,000 work abroad part of the year and as such it is difficult to determine the work which they do, without double counting as divers in other areas. The US Gulf of Mexico offshore activities are cyclical (seasonal) as are the North Sea operations. This causes a heavy work load for four to five months a year. The distribution of the activities for which these divers are employed is assumed to be similar to the North Sea figures shown in Table 3.4, but with less work in the area of inspections,reflecting the lack of US regulations requiring certification inspections on the North Sea fields. This results in a larger percentage of the work being allocated to pipeline inspections, since these are often performed in the US by "live-boating" with divers, a practice not allowed in the UK or Norway, but allowed on a restricted basis in the US. Using surface supplied mixed gas or air, "live-boating" is basically the diver walking the line while the diver support vessel moves along. Table 4.11 indicates that of all North Sea inspection work, approximately 34% requires saturation divers. A corresponding 20% figure for the US would be due to the shallower depths encountered on the US Gulf of Mexico (where almost all structures are in less than 100 meters of water).

TABLE 4.12

MODES OF ACCESS OPERATED BY COMPANIES[c] (NORTH SEA - 1977)

Type of service offered	Number of companies covered	INDICATED SCALE OF OPERATIONS	
		Total number of divers	Number of inspector divers[a]
Underwater inspection and construction			
With divers, submersibles and ROVs	3	389	47
With divers, submersibles	2	246	58
With divers and ROVs	4	223	26+
Divers only	11	374	113+
ROVs only	4	-	-
Submersibles only	2	-	-
	26	1232	244+
Underwater construction only	12	770	51[b]
Total divers		1932	

Notes: a - Included in total number of divers shown in previous column.
b - Some companies in the category do have inspection capability which is not currently used in their North Sea operations.
c - Excluding 2 "new" companies and 5 known non-respondents.

Source: CIRIA UR-13, p 59.

4.3.3 Manned Submersible Utilization

Data on manned submersible excludes use of ADSs, used predominantly on the North Sea to date. These systems have been used primarily in support of drilling operations with some reports of inspection jobs and site/debris clearance. Similarly the use of MDUs has been for drilling support.

As will be shown in section 4.3.4 the use of free-swimming manned submersibles, both the regular and DLO type, have a significante role in structure and pipeline inspection/surveys.

The manned submersible is generally more capable than ROVs but the vessel size presents access difficulties at tight locations, and manned subs are not used within the perimeter of a jacket type structure. For these reasons the manned subs are often used for inspection of jacket exteriors.

The use of DLO submersibles, carrying up to 5 persons (one pilot, two observers, and two divers) has been primarily for bottom orientated work, requiring the sub to settle into a stable configuration on the bottom. Recently they have been used for mid-water activities. The sub is fitted with a special attatchment which straps it temporarily to a platform member at the desired work site. The manned submersible is normally utilized to exploit its high degree of mobility moving around sites with the mothership tracking it. It has greater depth capabilities than most fields require and provides competing services with ROVs for pipeline surveys, routes, inspections, etc.

Detailed data for the US manned submersible usage during the past few years has been published. Table 4.13 indicates approximately overall utilization for these systems.

TABLE 4.13

U.S. MANNED SUBMERSIBLE UTILIZATION*

Year	Total dive days	Civilian	Military
1973	-	230	-
1974	-	290	-
1975	545	355	190
1976	-	498 (888 dives)	-
1977	-	676 (899 dives)	-
1978	-	510	-

* approximate

Source: Richard A. Geyer Ed., Submersibles and Their Use in Oceanography and Ocean Engineering (Amsterdam 1977) p 361.

Missions for the US Navy's manned submersibles during 1975 were in the following categories, with the indicated relative percentages of the total Navy usage:[48]

Training and Test	34%	
Inspection	36%	
Scientific Research	14%	
Engineering	12%	
Geology	4%	(totals 100%)

The Navy utilization areas may be contrasted to the data in Table 4.14, showing utilization areas for civilian work, for manned submersibles during FY 1973, 1974, and 1975. These are less orientated towards oil and gas operations (on a percentage basis only) than similar data would be for the North Sea area.

TABLE 4.14

CIVILIAN MANNED VEHICLES UTILIZATION CATEGORIES

U.S. only: FY 1973, 74, and 75 (reported dive days)

Use Category	FY 1973	FY 1974	FY 1975
Coral harvesting	43	74	91
Training or test	46	62	34
Inspection	21	37	106
Fisheries	29	34	15
Geology	39	21	52
Biology	37	21	11
Pollution	5	12	17
Engineering (salvage, recovery cable burial)	10	29	28
Annual Total	230	290	355

Source: Richard A. Geyer, Ed., Submersibles and Their Use in Oceanography and Ocean Engineering (Amsterdam 1977) p 361

Busby has reported that of the 510 manned submersible dive days (in the US) recorded for FY 1978,28% were funded by the federal government, 24% were funded by private research foundations, and 51% were funded by private industry.[49] This 51% or at the most 260 dive days, could have been for oil and gas associated work, although the figure would be less than that since submersible development is included. Contrasting this is the reported 444 machine days contracted during 1977 for the North Sea oil and gas activities for platform inspections, along with 283 dive days for pipeline inspection efforts. The total for North Sea inspection needs is 727 machine days.[50]. North Sea subs are also employed for route surveys, construction assistance, and other categories.

The US FY 1978 figure of 510 dive days may be compared to a total reported approximately 2,000 ROV machine days legged in the US by approximately half of the ROVs operating in the US. All of this usage was privately funded by industry users or for testing systems aimed at the industrial market.[51]

DLO usage is expected to increase due to recent improvements in diver heating apparatus, gas recirculation systems, and power storage capabilities. The major problem with DLOs has been short mission duration limits (on the order of 30 minutes of diving on the original vessels). These have improved drastically, to at least four or five hours.

4.3.4 System Utilization for Underwater Inspection of Structures and Pipelines

The inspection of structures and pipelines has been the subject of speculation regarding the market size. This is not only due to the North Sea operators' serious concern with structural integrity, but also with a general expectation that this will provide work for the underwater service firms in the near future as new construction on the North Sea winds down. The volume of long-term needs is not known, because much of the current work is carry-over from initial construction or field expansion combined with revisions to risers, cathodic potential systems, etc. The following discussion is based on a report produced by the CIRIA Underwater Engineering Group, aimed at assessing the market for inspection services, based on a survey of the intervention methods practiced during 1977 and 1978. It provides valuable information on the means of access utilized for this potentially large application of all modes of access.[52]

TABLE 4.15

ESTIMATED VOLUME OF UNDERWATER

INSPECTION WORK ON STRUCTURES 1977

NORTH SEA ALL AREAS REASON FOR INSPECTION	ESTIMATED VOLUME OF INSPECTION BY THE VARIOUS MODES						
	Inspector Divers		Other Divers		Manned Submersibles		ROVs
	Air Diving Man-Days (M-D)	Sat. Diving (M-D)	Air Diving (M-D)	Sat. Diving (M-D)	STD M/C Days	DLO M/C Days	M/C Days
Construction	93	-	981	473	90	24	15
Certification	3903	3006	6908	3077	216	-	211
Repairs	254	-	751	163	58	56	80
Totals	4250	3006	8640	3713	364	80	306

Note - Diving efforts include all men who make dives, i.e. an 8 man team working one day equals 8 M-D.

Source: CIRIA UR-13, Table 7.

Table 4.15 indicates the approximate volume of inspection work carried out for the underwater inspection of North Sea structures during 1977. Because of the large number of ROVs which were made available between 1977 and 1979 (approximately 80 new vehicles were produced in this period) the current equivalent figures are assumed to be more orientated toward use of ROVs.

On a cost basis, the reason for the inspection of North Sea structures (for all areas combined) are divided on the following proportions:

Inspection during Construction and Installation	12.5%
Routine and Certification Inspection	75.0%
Inspection of Repairs	12.5%

TABLE 4.16

DIVISION OF U/W INSPECTION WORK - MODES AND

REASON FOR STRUCTURE INSPECTIONS

REASON FOR INSPECTION	PROPORTION OF TOTAL EFFORT BY VARIOUS TRANSPORT MODES				
	All Divers		Manned Subs		ROVs
	Air Diving	Sat. Diving	L/out DLO	W/ DLO	
Construction	8	7	24	30	5
Certification	84	91	59	-	61
Repairs	8	3	17	70	26
Total	100	100	100	100	100

Source: CIRIA UR-13, Table 11.

Table 4.16 indicates the percentages of inspection work carried out on all structures on the basis of reason for the inspections and the mode (system) by which the inspection is carried out. The high proportion of all system usage identified with the certification inspection is due to the operators combining their own assurance needed inspections with the regulatory authorities' needs, as explained in section 3.2.5.1. The inspection for certification purposes is the major effort for the North Sea structures. Because of this it is important to realize the relative task composition of this work. The post-installation inspection and post-repair inspection is given in Table 4.17. For the North Sea structures there is much work that is observation only, which is indicated by a dashed line (box) on Table 4.17. Approximately 13% of the effort on Southern North

Sea structures is below the splash-zone and consists of observation. Similarly for Norther sectors, the corresponding amount would be almost 50%. This work would be within the capabilites of most if not all ROVs. Other work includes some cleaning effort, which is also within the capabilities of the more sophisticated ROVs, such as the SCORPIO or TROV, etc. The report from which the tables are taken indicates that at the time of writing, "some vehicles claim a cleaning capability, although it is understood that this potential skill has not been used extensively."

TABLE 4.17

PATTERNS OF UNDERWATER ACTIVITY FOR CERTIFICATION INSPECTION IN 1977*

INSPECTION ACTIVITY	PROPORTION (BY VALUE) OF TOTAL EFFORT		
	Steel Jackets		Concrete Platforms
	S 56°N	N 56°N	
General visual survey			
Air/splash zones	44	6	85 (Air/splash zones and Other)
Other	-	22**	
Cathodic potential Readings	5**	19**	-
Scour map	8**	9**	10**
Close Visual Insp.			
Cleaning	21	38	5 (Cleaning and Inspection)
Inspection	6	6	
NDT of nodes			
Additional cleaning	10	-	-
Inspection	6	-	-
Total	100	100	100

* Based on operators estimates and anticipated NDT programs.
** Within "eyeball only" ROV capability.

Source: CIRIA, UR-13, Table 16

This capability is certainly within the capacity of many more vehicles at this time, and although no reports of high utilization of cleaning capacity have been obtained, this is suspected to have been an area of immediate ROV improvements. At least two vehicles (previously noted) have the capability, and are offered for performing this task.

The actual amounts of system contracted work for the inspection of structures for certification purposes only is given in Table 4.18.

TABLE 4.18

VOLUME OF ALL UNDERWATER INSPECTION EFFORTS

NORTH SEA STRUCTURES IN 1977 (FOR CERTIFICATION INSPECTION ONLY)

Mode of Transportation	Volume of Work	
	Quantity	(Units)
Air Diving	10800	Man-Days
Saturation Diving	6083	Man-Days
Manned Submersible	216	Machine Days
Manned Submersible w/DLO	-	Machine Days
ROV	211	Machine Days

Source: CIRIA UR-13, Table 10.

This includes all North Sea areas. Similar data for the US and other areas was not obtained. In order to assess the role that ROVs and other non-ambient divers perform, there is a need for a measure of work to cross reference or correlate the machine-days and man-days listed in Teble 4.18. This is not really possible due to the variety of vehicle capabilities and the greater ability of the ambient diver. In lieu of such measures the only means of estimation of ROV roles is by the reduction of non-ROV use and the increase of ROV usage.

Estimates of changes in the make-up of services due to the range of abilities of ROVs are given in Table 4.19. These were provided by offshore field and service company operators who participated in the CIRIA survey.

TABLE 4.19

CHANGES IN MODE UTILIZATION FROM 1977 TO 1978 FOR

CERTIFICATION INSPECTION OF STRUCTURES

Mode	Change 1977-78 % increase of use	Measure
Saturation Diving	-13	Man hours
Manned Submersibles	+76	Machine hours
Unmanned Vehicles	+149	Machine hours

Source: CIRIA UR-13, Table 18.

These figures may in fact be lower than the actual changes that have taken place. However, no data was obtained to bear this out.

Pipeline Inspection

Pipeline inspections (excluding risers) are well adapted to the use of manned submersibles and ROVs. They may be carried out by towed sonic devices, such as the numerous side-scan sonar designs, which themselves are being constantly improved. Recently introduced civilian systems allow for high quality perspective corrected output produced by micro-processor based technology. In addition to being used on a towed fish, an ROV may incorporate this capability as a sub-system.

The use of ROVs for pipeline inspection promises to be a major application of these systems. A major problem with the use of ROVs is the entanglement of the tether by debris, in a structure, or on the support vessel. This is not as critical with pipeline inspection, which usually entails "flying" along the line and taking video, c-p, and trench profiler survey data.

Data presented in the CIRIA inspection report reflects these views also. Neglecting the start-up and installation phase inspections (also neglicting pre-construction survey/inspections) the inspection of pipelines is primarily for routine and post-repair requirements. These are carried out by the means listed in Table 4.20, based on the value of the total contract costs. This accounting tends to reflect the system costs, but the degree of this distortion is not accounted for. Based on the existing length of installed pipelines and the planned construction (estimated by CIRIA in 1977/78) the pipeline inspection needs for routine inspection only are given in Table 4.21. This shows a predicted increase in the amount of the jobs which will be carried out by ROVs, manned submersibles, and saturation divers, at about the same relative share of the work until 1980.

For general inspection only, estimates of encroachment of the ROVs and manned subs into the saturation diving share of the work predict up to 30% of the saturation work being shifted to ROVs and manned subs by 1980 (from 1977). This is not incorporated into Table 4.21. After 1980, saturation diving work is expected to stabilize for North Sea structures, which will have been in place long enough to have generated an adequate data base. Manned submersibles and ROVs are expected to capture any increased work load.

TABLE 4.20

NORTH SEA PIPELINE INSPECTION: MODES USED AS A

PERCENTAGE OF TOTAL VALUE OF INSPECTIONS

TRANSPORT MODE	Routine Insp.	Post-Repair	All
Air Diving	4	3	3.8
Saturation Diving	13	16	13.7
Manned Submersibles	46	17	38.1
Manned Submersibles w/DLO	11	57	22.8
ROVs (incl. bottom crawling vehicles)	17	0	12.9
Towed Sonic Devices	9	7	8.8

Source: CIRIA UR-13, p 54.

TABLE 4.21

NORTH SEA PIPELINES - ROUTINE INSPECTION EFFORTS

Forecast based on installed length plus forecasted milage.

TRANSPORT MODE	UNITS (CONTRACTED)	VOLUME OF ROUTINE INSP. WORK*		
		1977	1980	Mid-1980's
Air Diving	Man days	x = 729	1.0 (x)	1.23 (x)
Saturation Diving	Man days	x = 354	1.58 (x)	3.46 (x)
Manned sub.	Machine days	x = 156	1.40 (x)	2.78 (x)
Manned sub.w/DLO	Machine days	x = 36	1.58 (x)	3.47 (x)
ROV (incl.bottom crawling)	Machine days	x = 109	1.58 (x)	3.65 (x)
Towed sonic devices	Machine days	x = 214	1.14 (x)	1.78 (x)
Pipelength (MI) S 56°N		L = 813	1.0 (L)	1.23 (L)
Pipelength (MI) N 56°N		L'= 954	1.58 (L')	3.46 (L')

*Note: 1 diver gives 60 days per year. 1 machine works 84 days per year 4 to 6 divers are used per spread day, i.e. diver man days include full crew in addition to single worker.

Source: CIRIA UR-13 p 55.

In summary, the data for inspection of North Sea structures and pipelines gives some indication of the relative utilization of systems, for this single, although substantial, area of application. The role of ROVs is not clear for the future; however, the nature of the inspection work - planned, not on the critical path, etc. allows for substitution of ROVs more than for other underwater activities.

4.3.5 Summary

There is no hard data available for determination of the utilization patterns for the different modes of underwater intervention. They have been compared on the basis of what areas seem to be major applications for each system. Table 4.9 shows this information as accurately as can be determined from the source data.

The prime areas for ROV usage are as substitutes for divers for inspection tasks and as diver assistance systems for any non-observation tasks or tasks beyond simple manipulation situations.

A major determinant of substitution potential is the degree of sophistication of the ROVs manipulator systems. As the current ROV population is utilized, observation tasks will be carried out by ambient divers on a decreasing scale, and this will occur at shallower depths as cheaper systems become available.

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5. SAFETY IMPLICATIONS OF UNDERSEA TELEOPERATORS

5.1 Introduction: Safety of Underwater Operations

The safety of underwater operations and the potential for safety improvements in offshore underwater operations is a broad topic which will be treated only cursorily. This is a complex and difficult topic, in a rapidly developing field. The real benefit of the utilization of remote underwater systems is the decrease of risk to human life. This is not necessarily the current motivation for their use, but is a real benefit.

It should suffice to say here that for manned submersibles due to the combined efforts of classification societies, operators, and constructors, along with government sponsorship of a collective effort at being prepared for emergencies involving vehicles, a high standard of safety in design, construction, and operation is being achieved. The result of this has been a good safety record over the past four years. The substitution of ROVs for manned submersibles presents a safety improvement in the most general sense, that if a man is not in the water, (or sub), the activity or operation is made safer.

Since the bulk of non-military underwater operations are carried out for the oil and gas industry, the aim of this section is to identify some of the considerations which are usually lumped together and called "safety", to determine some of the more important areas of underwater risks, and to analyze how the risks may be reduced. With the high risks identified, the availability and utilization of ROVs is assessed as a possible solution to the problem. Although they are not found to be applied in a highly effective manner, the potential role of ROVs is clarified. This report is limited to the study of the heavy-industry related safety issues and the role which ROVs may play in the immediate operations.

Looking more closely at the safety considerations, we see that in many industrial cases the real motivation has not been to outright avoid risk to lives, but rather to take advantage of the fact that a system is cheaper, since sophisticated means of life support are not necessary. Although it would be "nice" if the primary concern was with lives (as lives), this is really not the case. This may be substantiated by the fact that although the risks to humans due to accidents, etc., are the same or as high for shallow water situations, the deployment of ROVs and other systems is determined purely on a basis of cost to the contractor. This will be substantiated in section 5.3.2, but costs must be considered as the underlying motivation for the use of unmanned systems.

The use of ambient-divers in the offshore development has been practiced for many years. During the initial work in the North Sea the bulk of the operations were south of 56°N and the diving was predominantly surface supplied air mode, or mixed gas on a more limited scale. As the operations reached north of 56°N, there was an alarming increase in the fatality rate among divers. At what appears to have been a peak in the accident rates, the statistics showed one fatal accident per one hundred divers per year. In 1975 there were 10 fatalities among 700 industrial divers at work on the Northern European continental shelf.[1] Since that period the population of working divers has risen, while the fatality rate has not increased. Still this created a strong impetus for making changes in the safety of offshore underwater operations, and for development of regulations to control the activities. The diving regulations will be discussed in detail in section 5.3.3.

The motivations for development of submersibles and ROVs have included the need to remove the man from the ambient pressure, and in doing so eliminate the need for exotic systems of support. Also the alternate systems may offer more desirable characteristics, such as better payloads, power, and longer mission durations. For depths of less than approximately 1500 feet, ambient diving is possible, and the choice of between diver or alternate system is based on two considerations, one equipment cost, and two, the cost of the safety of the man in the system. We do not usually look at the cost as two separate amounts, as cost of safety is a marginal cost on many systems. But it is useful to consider explicitly the cost of the margin of safety we allow for, which usually is incorporated into the cost of operation.

We next examine some of the underlying assumptions concerning the safety benefits of use of ROVs.

5.2 Underwater System Safety

Safety for ROVs has meaning primarily in the sense of the change in safety by no longer requiring a man (ambient diver) to be used in the water. For diver assistance, this is not the case; the vehicle may provide an improvement in the safety of the diving operation. But in general the safety due to ROVs being utilized is really meant to be with regard to the improved level of safety of an unmanned activity over a manned one. In any case, it is necessary to refer to that situation where a human being is in the system (or activity) for the concept of safety to have meaning.

With this as a starting point, we examine the activities that utilize divers and are known to be risky, and determine just how ROVs are able to improve this unacceptable or less than desirable safety. In doing this we may temporarily ignore those areas which are simply beyond the range of current ambient diving. Thus future diverless systems, say for deep-water production, are not really considered as safety improvements, since this is not now an active area of diver usage.

Safety is the condition of being free from harm or risk of harm. In underwater operations, involving diving systems, the "risk" has been further defined as the product of the probability of an incident times the consequences of the incident.[2] "Consequences" defined rigorously means the disutility of lives lost, morbidity (injuries), or dollar-costs combined. In the simplest case we can refer only to lives lost. The use of an ROV is difficult to insert into the risk equation for a diver or underwater operation where there are no data on fatalities. Based on historical data for various diving modes, some underwater operations present a higher level of risk to divers than others. Based on this, the rational use of ROVs should be to aim the development of the systems at the most dangerous operations.

The diving carried out in the US has not been subject to <u>any</u> official record keeping,making such a focus difficult. In the UK there is some data, but the relatively recent development of the techniques precludes any conclusive analysis. In the face of the lack of information with which to make decisions, the offshore industry has had the option during design, to spend to more than is minimally (politically or socially) necessary to reduce the risks.

Ideally when the designer or operator recognizes the potential exposure of divers to a dangerous situation, there may be some choice of methods to decrease this exposure or eliminate the exposure completely. Figure 5.1 illustrates an idealized situation where if one group had

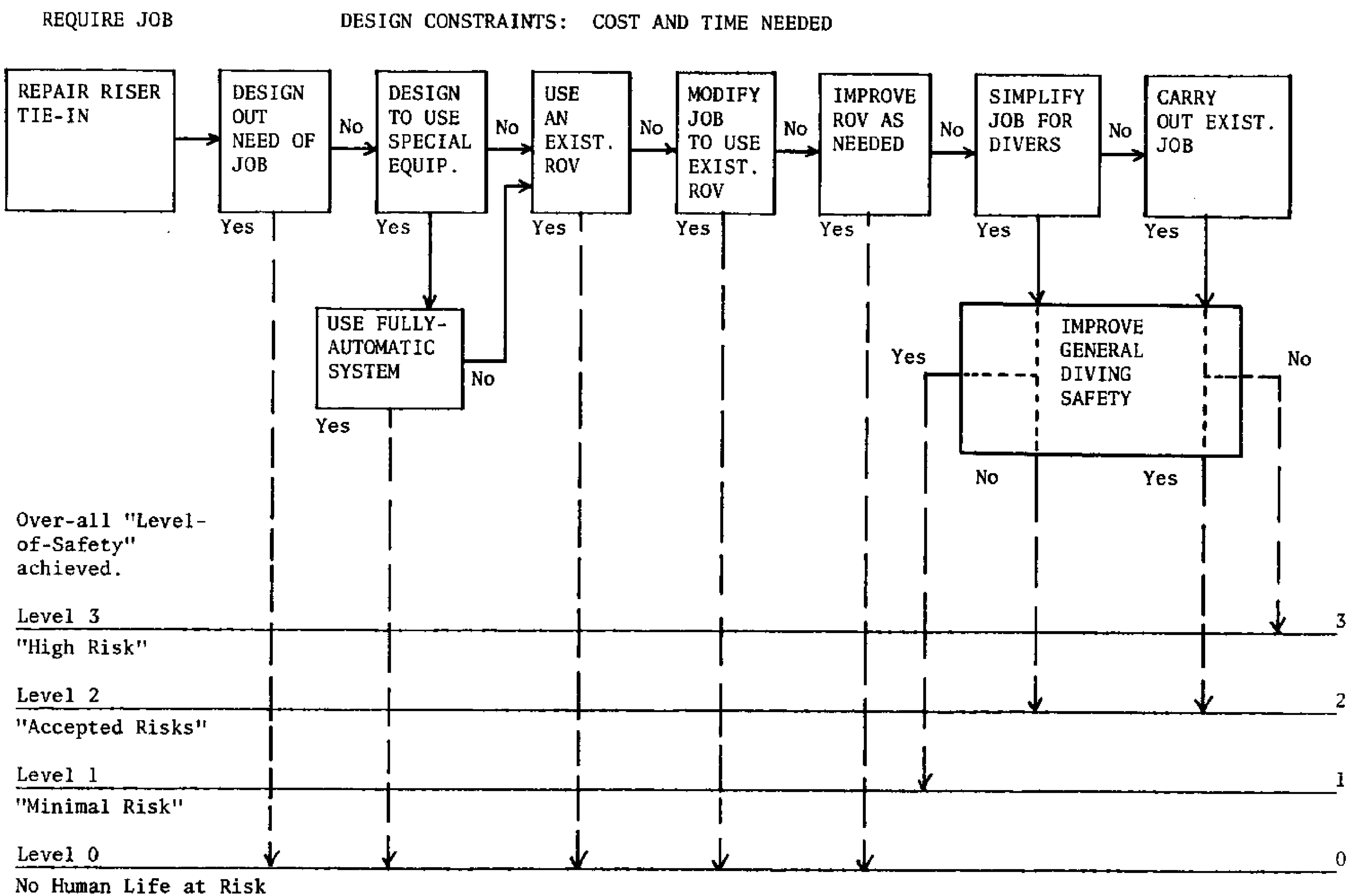

FIGURE 5.1 - CHOOSING SAFETY OF OPERATIONS.

control over the many functions which are in reality spread among contractors, choices could be made to determine the safest method of doing the job. This is idealized since time and cost constraints require a "no" answer at most of the decision points. The need for adequate planning indicates an area of general safety improvement by use of increased management continuity on projects with underwater activities.

Figure 5.1 is self-explanatory and will suffice for the general approach to the problem. The main determinant of whether a route will be taken is the cost of changing or experimenting with new methods, since in most cases at least one method has been tried before and works.

Given the options shown in Figure 5.1,we are concerned with the fundamental choice between use of the diver vs the use of an ROV. Since the risk decrease obtained by using an ROV is evident, we need to examine the costs that determine the choices between them. A real force behind the cost is the level of safety required in the manned operations, often determined by regulatory requirements. To understand this we need to examine the methods by which the ambient diving operations are carried out.

5.3 Ambient Diving

5.3.1 Diving Modes

Depending on the depths of the work, there are three modes of diving practiced. The definitions used are not exactly the same as those commonly used in the literature, but are used here to demonstrate the important differences between these modes.

For short duration shallow water diving SCUBA is used. This is not one of the three major commercial techniques, but it is being used by the US offshore industry.

Commercial shallow water diving is carried out by long exposure dives using surface supplied air or surface supplied mixed gas. Within certain total exposures to depths, the diver may ascend at a rate of 60 feet per minute and not require any further treatment other than the restrictions on the period before the next dive.

In the absence of government regulations the surface supplied air diving may be carried out to depths of hundreds of feet, with minor side effects, if the ascent is properly drawn-out. However, due to the nitrogen in air, certain ill-effects occur, and so a mixed gas is used, helium/oxygen, or heliox.

When the dive is to a greater depth,the increase in pressure forces the inert gases in the air and breathing mixtures to be dissolved and be absorbed in amounts that are higher than the case at atmospheric pressures. Subsequent return to a lesser ambient pressure can cause much of this absorbed gas to come out of solution in the form of bubbles within the blood, which are generally considered to be the cause of decompression sickness and other related disorders. These problems are minimized by controlling the ascent of the diver and permitting the gas to come out of solution slowly.[3]

Because this decompression takes time, the industry practice has evolved into two general "deeper" work methods. One,for short duration jobs, is to minimize the time at pressure by quick descents and ascents, and thereby minimize the amount of inert gases absorbed, which determines the amount of decompression time. The result is the Deep-Bounce (short exposure) dives. These may be made to depths of 500 to 600 feet and are called "deep and dirty" because of the quick exposure to depths and the lengthy decompression, along with the occasional neuromotor disorders during compression.[4]

Although it is a favored method for getting the short jobs done, this method is not kind to divers. "Many incidents of bends have been reported with deep bounce dives. On some jobs there are reports of up to 30% incidence, which emphasizes the difficulty of performing safe decompression in deep water."[5] The potential dangers of these dives are high since the operator must rely on the diver returning without delay, etc., and a problem down at the bottom will require long decompression times to undo it.

The second method for deep water diving also uses mixed gas, and is saturation diving, where the divers are kept at the pressure of the work/task depth between dives, by use of a personnel transfer capsule, or submerged compression (decompression) chamber. This technique is used in order to let the inert gases reach a saturation level, after which the decompression time is not increased over a maximum. Decompression from saturation requires one hour per 6 feet of "storage" or saturation depth. Saturation systems are large and expensive and require a large well trained crew to operate them.

The marginal use of saturation is expensive even when the capability is on hand, due to high rates of pay for the divers, on a depth basis, and the high cost of gases (required to be compressed for use). Because of the high costs involved, the use of saturation is avoided when possible, by use of bounce techniques, if regulation permits.

The choice of the depths to which the modes are used is the heart of the diving safety issue. Table 5.1 illustrates the variations of the regulatory requirements for the use of systems, by indicating some of the more critical equipment or cost effecting points of the US, UK, and Norwegian commercial diving regulations.

TABLE 5.1

COMMERCIAL DIVING REGULATIONS: DEPTH/MODE RESTRICTIONS, RESTRICTED PRACTICES

Region/ Reg.Body	Use of SCUBA	Mode: Surface-Supplied Air (SSA)	Mode: (SSM) Surface Supplied Mixed-Gas	Use of D.D.C.[1]	Use of S.D.C. (Bell)[3]	Mandatory Saturation Rules	Live-Boating Rules	Other
US Coast Guard (2-01-79)	D_{max}= 130 fsw	$T_{unlimited}$ D_{max}=190 $T \leq$ 30 min D_{max}= 220		1) req'd for SSA if $D > 130$ 2) req'd for SSA if outside N-D-C[2] 3) req'd for SSM if no bell available	1) A bell (open) req'd if $D \geq 220$ or $t \geq 120$ min 2) Closed bell req'd if $D \geq 300$	None	D_{max}= 220 (day-light only)	None
US OSHA (20-10-77)	D_{max}= 130 (DDC req'd if $D > 100$)	$T_{unlimited}$ D_{max}=190 $T \leq$ 30 min D_{max}=220		1) req'd for SSA $100<D<220$ 2) req'd for SSM for $D < 300$ 3) req'd if outside N-D-C 4) req'd all diving $D > 300$	1) SSA bell req'd if $t > 120$ min 2) SSM: req a bell if $D > 220$ $t > 120$ 3) Closed bell req'd if $D > 300$	None	1) $T_{unl.}$ SSA D_{max}=190 2) $T \leq 30m$ SSA D_{max}=220 3) SSM D_{max}=220	None
UK (1975)	Prohi-bited	D_{max}=164		Req'd available on site	Closed bell req'd if $D \geq 164$	Yes See note 6 below	Prohi-bited	Hyperbaric rescue transp. to be req'd under HSC[4]. State permission for all $D > 410$[9]

- cont'd -

TABLE 5.1 (cont'd)

COMMERCIAL DIVING REGULATIONS: DEPTH/MODE RESTRICTIONS, RESTRICTED PRACTICES								
Region/ Reg.Body	Use of SCUBA	Mode: Surface-Supplied Air (SSA)	Mode: (SSM) Surface Supplied Mixed-Gas	Use of D.D.C.[1]	Use of S.D.C. (Bell)	Mandatory Saturation Rules	Live Boating Rules	Other
Norway (1977-Draft)	Prohi-bited	D_{max}=164 with daily time limits	Time limits per 24/12 hour period	Req'd available on site	1) Closed bell req'd if D ≥ 164 2) Req'd if tender is 5 m above water line	Yes See note 7 below	Prohi-bited	Umbilical length restricted to 29 m max diver w/31m tender. Hyperbaric rescue transp. req'd, see note 5 below. State permission for all operations.[8]

D = Depth (fsw) T = Bottom time t = Decompression time

Sources: Great Britain, Statutory Instruments 1974 No. 1229, Offshore Installations, "The Offshore Installations (Diving Operations) Regulations 1974."; Norway, Directorate of Labour Inspection, Draft: Offshore Diving Regulations March 17, 1977, unofficial translation; US, Department of Transportation, Coast Guard, Commercial Diving Operations, U.S. Code, Title 46, Part 197, Nov. 1978; US, Department of Labor, Occupational Safety and Health Administration, Commercial Diving Operations, U.S. Code, Title 29, Part 1910, Subpart T, July 1977.

Notes:
1. US Deck Decompression Chamber (DDC) is equivalent to UK and Norwegian "compression chamber".
2. "N-D-C" denotes no-decompression dive table restrictions on bottom times are not exceeded.
3. "Bell" denotes open or bubble type bell, "Closed bell" denotes sealed type bell.
4. UK HSC reorganization of occupational safety rules will include provisions for hyperbaric rescue/transp.
5. Must be utilized when technology is commercially available.
6. Saturation diving required if diver remains under water for an aggregated period in excess of 3 hrs.
7. Restricted according to working hours in water per 24 hrs.
8. Specifics of plant and equipment procedures to be approved in advance by Director of Labour Inspection.
9. At depths greater than 125 m procedures to be approved by Secretary of State.

The differentiations between regulatory requirements are probably less critical at the deeper end of the commercial range, say at 800 to 1000 feet, since company policies are quite strict at these depths. However the real questions lie with the limitations on air, bounce and start of saturation techniques. The use of ROVs, when sufficiently capable for manipulation, would, and to a degree does so today, depend on the cost-effectiveness of the ROV. The cost effectiveness of the ROV will be partially determined by the cost of marginal safety improvements of the diving operations. These would include costs for safety related equipment such as stand-by or back-up equipment, or even items like a deck decompression chamber, which a contractor may not always feel is necessary to have on-site. These safety costs of diving help to determine the use of alternate systems such as the ROVs. Figure 5.2 illustrates the decisions made for choosing a system for a simple underwater task, where the surface diver may be competitive with the ROV. Primarily this would be for simple tasks, given today's manipulative capacities on ROVs, but it may be generalized to future situations. If Region B has less strict controls on diving practices, there is less incentive for using an ROV, regardless of so-called safety arguments. The arrows on the graph of Region B costs do show a long-term inevitable trend, that is, the machine costs will go down, and manipulative capacity will go up, at the same time the cost of ambient divers will rise, due to increased regulatory controls, and also due to the generally more inflation-prone costs of labour. Eventually these trends will compel the use of ROVs in shallower areas. Where ROV systems are now on such charts is hard to say. Most probably for a medium to complex manipulative task, with good planning, the operator on the North Sea today would do well to find a vehicle to be available for the task at depths

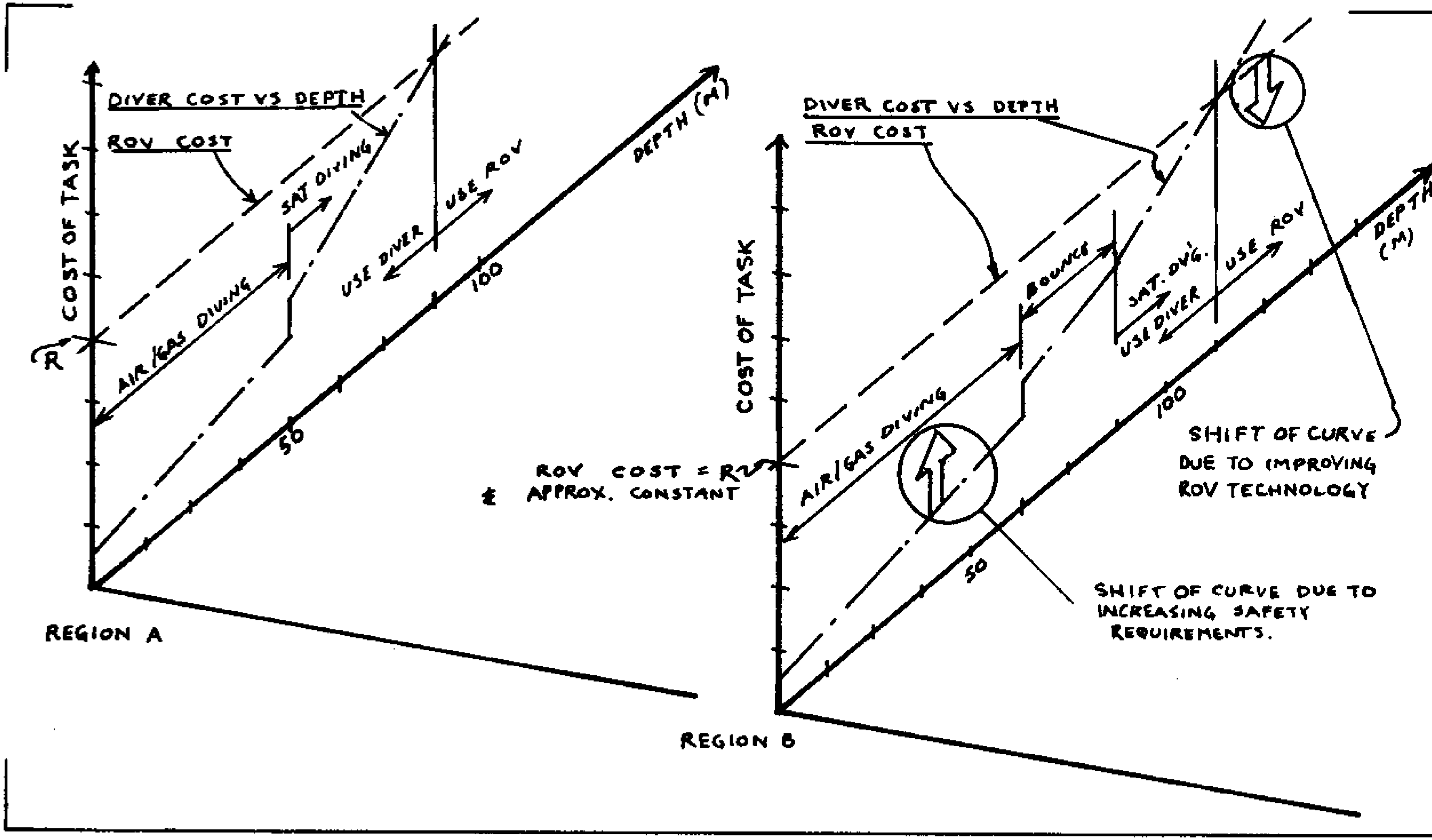

FIGURE 5.2 CHOOSING SYSTEMS: DIVER COST VS ROV COST. For an assumed task within an ROV's capability, the cost-effective depth for the ROV will be dependent on local regulations. Region B is shown as a less strict area allowing less expensive diving. Region A is shown as a more strict area requiring more expensive diving and use of ROV at shallower depths. Arrows on Region B indicate long term curve shifts.

of 300 to 350 feet. However one major diving contractor who was questioned on the competition of ROVs felt the current arena was in the 300 to 600 foot regime.

5.3.2 Risks and Accidents

The estimated risks at different depth regimes need to be assessed with the above concepts of cost interactions requiring the use of ROVs for safety purposes.

First the overall depths may be considered. Most activities involving divers are in less than 200 meters water depth. In the US, the depths are even less than this on the average, with the yearly average depth subject to some major projects requiring a heavy saturation diving load. Otherwise a large portion of the US work is on air. Diving seems to be safe (this does not account for long term risks such as increased risk of bone damage) physiologically to depths as deep as 500 meters, however these are not and will probably not for a long time be commonly used depths.

Beyond these depths the limitations are simply not yet known. However there are not any major difficulties with carrying out a saturation operation at depths of up to nearly 1100 feet, as was done in 1977, for the COGNAC project. Instead the limitation are economic. It gets very expensive to pay depth pay, gas costs, and decompression costs. Beside cost considerations overriding safety, there do not seem to be any inherent dangers in the deeper regimes which are sometimes reached today for the extreme projects. The care exercised must be increased and the statistics improved on the serious long term effects from deeper dives. However, the overriding motivations today seem to be the economic ones. The following ideas seem to even reverse the assumption that deeper is more dangerous.

Even with little data to go on one thing is clear; the shallow depths where air or surface supplied mixed gases are used, without a bell, may present a very serious risk. A comment by J. Warner, the chief diving inspector of the UK Department of Energy, emphasized that "air (so-called simple diving) produces as many if not more accidents than very deep diving. A breakdown of North Sea accident figures suggests that over the last five years at least 50% of all the accidents occured in air diving. When one goes further and analyzes the number of hours of exposure in saturation diving in particular, for man hours under pressure, air diving is considerably more dangerous than deep diving."[6] This source does not indicate the relation between dives and saturation hours (to account for storage at depth) and so the applicability of this statement is limited.

Another study performed by Det norske Veritas found that (by use of fault tree analysis with "perfect crew" assumptions) the risk to life was at least an order of magnitude higher (in terms of fatal accident rates) when bounce diving techniques are used as opposed to saturation diving techniques.[7]

A similar but still supporting opinion was given by a representative of a major US diving company, heavily involved in habitat welding and construction support, who stated that "the saturation mode of diving is by far the safest and kindest to divers because they are only compressed and decompressed once over a period of time. And this procedure is carried out relatively more carefully than, say, if a diver were using SCUBA or bounce diving, where he would be down for a couple of hours and then back up on the surface."[8]

In the previous sections it was found that the costs of the more sophisticated ROV systems are relatively high, (in terms of capital cost, higher than many saturation systems), when compared to the ambient diver costs, at shallower depths say down to 350 or 400 feet. This makes it difficult to see where and on what ground the substitution for divers will take place, if our real measure was to be improving the safety of operations. But the cost controls the substitution. It costs too much, still; even for applications with very serious safety justifications.

5.3.3 Regulations

With these safety observations in mind it may be useful to review some of the regulatory differences between the commercial diving regulations in effect in the US and the UK/Norway. (Norwegian regulations are based on the UK example). The different regulations require saturation at different stages, e.g. the UK requires it for a man/hour per day working regulation (para.7-1: "No diver engaged in diving operations shall remain under water, and the employer of divers and the diving supervisor shall secure that no diver remains under water, for an aggregate period in excess of 3 hours in any period of 24 hours unless that diver is using saturation techniques"). Since the US OSHA and USCG are open to use of newer decompression tables, (normally designed to assist in making the bounce dive more plausible, not only to find out new safety levels), the US regulations do not specify a need for saturation techniques.

Other missing elements in the US regulations are glaring, such as the use of SCUBA, (see quote above), and the provision for live boating. These two items allow techniques to be used in the US which are out and out prohibited in the UK and Norway, where the same companies carry out similar work as in the US. Other differences such as the Deck Decompression

Chamber (DDC) requirements are as interesting. The UK and Norwegian attempts to get the use of emergency saturation safeguards implemented by use of hyperbaric lifeboats are also noteworthy, and absent from the US regulations.

As stated previously, the intent here is not to comment on what is safe and what is not safe. The intent is to determine the cost/safety relation for the ambient diver, and compare it to the cost of ROVs. Since this is the only mechanism by which the safety from use will result, we may see that the current capabilities and costs of ROVs have not yet developed well enough to provide a reasonable impact on diver safety, in shallow depths. This is a function of the diving technology employed and the relative strictness of the diving regulations. As the variations in regulations show, the impact of ROVs on the underwater safety will be determined by the local regulatory situation.

5.4 Utilization of ROVs - Summary of Safety Implications

The use of regulations to control some of the aspects of diving operations have been described as one of the determinates of the equipment which will be used for the diving operations. Other practical decisions, such as the current diving tables will be overriding in certain cases.

While the cost of regulation in the US has been disputed, there has not been any discussion of the moving of the cost curve which would cause an increase in the viability of ROV usage.

The safety offered to the operator by using ROVs is only a function of the displacement of the diver, or the added safety of diver assistance. For determining the role of the ROV in the safety "equation", ROVs must be used instead of divers. The depths at which this should be done are not really clear. The long-term assumption has been that the deeper situations require ROV for cost and safety purposes. It seems that the shallow situations require the ROVs also, for safety purposes. But the operators' basis of choice really is cost, and a real safety gain will not be made, whether by use of ROVs, or by elimination of some diving techniques until cost advantages are favorable.

Improvements in ROVs will make them more able to carry out the work of divers, but only at a higher cost than that of the ROVs currently available. This will cause even further dis-incentive for use, in the US areas, particularly. Major safety improvements must be realized by increased vehicle capabilities, lower costs, and stricter controls on the use of ambient diving modes.

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6. UNDERWATER INSPECTION OF INSTALLATIONS
THE ROLE OF REGULATIONS, AVAILABLE TECHNOLOGY, AND ROVS

6.1 General Considerations and Conclusions

The current use of undersea teleoperators includes application in support of inspection activities for offshore structures and pipelines. These include operators' assurance program needs and also include the fullfillment of regulatory requirements for certain jurisdictions. Regulatory policy for offshore development is determined in part by the availability and capabilities needed for performing regulation motivated inspections below the waterline. For the underwater inspections, the cost of the underwater activities is a factor in the determination of how well and how often a structure will be inspected. This section of the report is concerned with the following aspects of ROV development:

- Regarding how structures are designed, i.e. do they need to be inspected, and on what basis.
- How are the regulations for underwater inspection of structures determined, and what is the role of available technology, especially ROVs, in these decisions?
- Does the currently available technology fullfill the requirements determined by the above considerations?

Consideration of these questions does not produce a hard and fast conclusion that the technology is not adequate, or that inspection activities must be increased, etc. Rather, the conclusions demonstrate that, given the variety of environmental situations, some areas will require more careful and detailed inspection programs than others. The more conventional areas (and structures) are not themselves well understood (e.g. loadings) in engineering terms, but still the industry structures perform with a degree of certainty, such that structural failure of permanent installations is not a realistic problem. In frontier areas, where environmental data is lacking, there may be a need for more intensive inspection activities, either for the operator's own uses, or for the regulatory body's use. Existing practices on the North Sea have produced data for environmental and structural situations that were previously not encountered. The results, so far, have been that the structures have not been found to suffer from unexpected degradation. The future frontier areas must be subject to similarly high-intensive scrutiny, and inspection requirements must be made to account for the needed flexibility for changing with the dynamic development situations.

The regulations which will apply to the US OCS areas in the future will attempt to minimize the need for underwater inspections, by requiring a large degree of monitoring and control during design, construction, and installation. This could be an effective means for maintaining minimal risk of failure with the attendant risks to personnel and the environment.

The use of ROVs or any underwater access system for helping to assure a structure's integrity by inspection support activities is not necessarily seen as a viable practice. From the operators point of view, the <u>need</u> for inspection of offshore structures represents a "failure" on the part of the operator, since an adequate design, if possible, will be maintenance free (underwater), and as such the inspection program will only be useful for determining that the structure is not in need of repair, etc. If inspections were the intention in the operator's integrity assurance effort, inspection would be a badly thought out practice; certainly none of the present operators use this approach now. The regulator's needs for monitoring structural integrity make them somewhat more skeptical of actual conditions and as such require some inspection feedback. The operators should and will try to be as free as possible from the needs for inspection for any reasons other than irregularities such as collisions, major storms, seismic activities, or construction/ installation related incidents. Ideally the availability of inspection technology, or ROVs will not be an important element in the maintenance of structural integrity for a well designed production system. Considering the operators' financial risks, there is adequate motivation for maintaining a safe structure, in advance of any regulatory needs.

Where less information is established due to structure types or loadings, there is a corresponding increased need for more data on the structures' conditions, and so a more stringent inspection program is needed.

The existing ROV technology plays a minor role in the ability of the operator to provide a safe operation/structure. With the approach to structural safety that is described above, the role of the ROV is to assist in obaining the data needed, by a more economical means than now available. Serious questions are raised, however, concerning the value of the techniques and equipment used for detailed inspections, and use by ROVs instead of divers presents further doubts on the quality of data. As the NDT technology improves the ROV may become a cheaper delivery system.

6.2 The Role of Inspection

In general the role of in-service inspections is to provide data for further considerations, which may include (for offshore structures) the needs to confirm the adequacy of:

- design assumptions
- material properties
- fabrication standards
- installation and field work
- corrosion protection

or the need to detect damages caused by:

- accidents during operations
- maloperation
- inadequate maintenance

or the need to develop a maintenance plan.

These motivations are in support of the overall goals of verifying short term integrity and for verifying continuing integrity.[1] The interest in the information may lay with the operator or with a certifying agency, or with a regulatory body.

In the United States jurisdictions the use of regulations to gain assurance of the operators maintenance of structural integrity is a fairly new situation for the offshore oil and gas industry. So far this need has not had any impacts on the US OCS operators' underwater inspection programs, since there have not yet been any regulation based demands for underwater inspections. The level of inspection performed by the industry is at present a minimal effort, for industry justified reasons.

In other areas, such as the North Sea UK and Norwegian sectors, the situation varies. In these areas the need for extensive underwater inspection of structures has forced utilization of all means of access modes, as was examined in Sections 3.2.5.3,4.3.4 and listed in Appendix E. Although the level of inspection efforts in the different parts of the North Sea has been high there is reason to believe that for certain areas it may be reduced, an expected result of the dynamic character of inspection needs, changing with the level of information required. This has been indicated by DnV (see Section 6.3.1) and has also been mentioned in other sources, based on an operator's survey for information. CIRIA Report UR-13 states that "there is some reason to believe on the basis of the survey information that the inspection effort per platform may stabilize at a level of some 75% of the current level" (written in 1979).[2] The reason for this is that: "These companies realize that before soundly-based economic inspection programmes can be devised, they must have extensive information about the nature of their platforms and the environment in which they are operated."[3]

Similar arguments may be made for pipeline and riser inspections in some areas. In general there appear to be a host of problems associated with determination of the needs for inspection of pipelines and risers, since these designs have continued to present expansion, corrosion, and protective coating problems. These are not reported for the US OCS areas, but are occasionally mentioned in the trade literature for the North Sea sectors.

The general argument or approach for inspections is that as new conditions are encountered, whether due to depths, environmental loads, or structure types, the regulators will demand more information at least until the local structure or conditions are verified as conforming to the required performance goals.

The ROVs' potential contribution is to be a less expensive means of access. To what degree the availability of the underwater system for access influences the regulation formation is not really clear. However, the cost of gathering information is a consideration, for any needs beyond minimum requirements, and the regulatory requirements will reflect this.

6.3 Regulatory Requirements

6.3.1 General Objectives of the Inspection Regulations

Although the operator's needs for integrity assurance are fairly evident, the need for the regulatory agency to establish a required level of inspection activity is not so apparent. To limit the discussion to the links between the ROV technology and the maintenance of a level of offshore safety (including structural integrity) we must first establish some of the aspects of the regulation process. Regulation requires information gathering activities to support:

- the operator's assurance based data needs
- the regulatory agency data needs, to determine the compliance of the operator to required codes, recommended practices, or other specifications utilized along with specific regulations.

These activities require the technology necessary to gather the data, and as such the state of the art determines the feasible limitations on potentially useful data, sources, and volume.

Each country has a regulatory body requiring certification or verification of some kind for the condition of offshore structures, or generally for offshore development. In essence, they are all comprised of similar functional elements of the following types:

- statutory requirements for development of controls over the industry activities.
- government agencies with mandated responsibilities to ensure the compliance of developers to statutory guidelines, by issuing regulations, or guidelines, or advises, or by delegation of authority to another group for the purpose of carrying out similar activities.
- verification authorities to act as responsible agents of the regulator, capable of determining whether or not the activities are in compliance of regulations. For offshore structures this would include confirmation/verification of whether the structure has been constructed, operated, and maintained in a manner that fullfills the regulatory requirements.
- certification authorities, operating similar to the verification authorities, which may confirm that the structure is constructed, operated, and maintained within guidelines designed to provide adequate safety, etc., or within guidelines required by the regulations. Classification authorities also may be used for the checking of maintenance of the underwriter's standards.
- codes and standards, whether industry specific (i.e. American Petroleum Institute Standard) or more general codes (or rules),

such as those of the ASME or similar, for general application. These are used as inputs to the certifying authorities' rules or standards, and are also used for the basis or establishing of specification oriented regulations.

Specific structures for the regulatory systems for the control of offshore developments differ among jurisdictions. During the last five years or so, there have been a number of efforts at examining the US OCS related codes and regulations, in response to recent legislation with environmental quality measures, and the increased pressure for development of oil and gas on the OCS. These efforts have made comparisons between the various regulatory strategies, etc., and also have reviewed offshore development controls. They have considered the national and international mechanisms for regulation of the offshore development, including production and transportation of oil and gas, but mostly with a view toward economic impacts of regulations.[4]

Among these have been studies of the actual inspection practices for pipelines, structures, and risers. Although these have all been performed for Federal Agencies in order to help to assess the various aspects of development and regulatory needs, mechanisms, etc., very little has been transformed into regulatory practice, for the area of inspection considerations.

Recently the Marine Board Assembly of Engineering has completed a recommendations, and the USGS has implemented it, for a Verification Program for OCS structure . Although this is only concerned with the above water (when installed) portions of the platforms, it is concerned with making the offshore structure safe throughout its lifetime, and considers the need for controls during design, fabrication, and installation of structures.[5]

In addition, and subsequent to the Verification program recomendation, the Marine Board Committee on Offshore Energy Technology (COET) has issued a report which provides recommendations to the US Department of the Interior Geological Survey for underwater inspection requirements for offshore structures and pipelines.[6] These recommendations are for inspection regulations and are primarily aimed at gathering data in support of structural integrity assurances, and attempt to avoid any data gathering for other purposes, except under unusual situations.

The USGS Conservation Division performs its mandated responsibilities by issuing "OCS Orders" some of which are geographically specific, and some in general, but all by a similar process with review by the public through a conventional rule-making process, and by the use of lease stipulations.

It is beyond the scope of this report to examine the various criticisms applicable to the various regulatory systems which may be used in order to perform the USGS's responsibilities for regulation of OCS development. The method used relies on making sure the industry utilizes acceptable levels of safety in its operations by conforming to the regulations which the USGS promulgates. To do this "making sure" or monitoring activity requires technology, both for ensuring that the regulations are adequate (independent of public or industry supplied information), and for ensuring that the industry complies to the regulations, by forcing them to, for example, inspect the structures and produce information showing the adequacy, or by the USGS performing its own inspections (or having them performed for them).

These two areas, the need for data for regulation development or feedback purposes, and the need for data to confirm structural integrity of an installation are the two activities which require underwater access.

These activities are carried out to some extent independently of the operator's own inspection philosophy, which in the US areas has been, simply put, to design on the basis of not inspecting in any detail below the water line except for annual approximate cathodic protection surveys.

The USGS is now at a point where certain base-line standard data needs will have to be met by the operators. This will include reporting on the operator's structural inspection programs, including data obtained on fouling rates, incidence of damages, etc. This information will be most important in frontier areas, and will probably not require large adjustments to operators' programs for conventional structures in areas such as the shallow areas of the Gulf of Mexico.

The role of ROVs will be to decrease the cost of obtaining the inspection data. Availability of ROV technology appears to have been a small consideration in the COET recommendations to the USGS.[7] The reason for this is the structural integrity approach to the problem, which tends to eliminate the needs for inspection as far as possible, in keeping with the inability to make structural modifications after installation. Still the USGS must provide for an inspection program.

The rational for an inspection requirement is partially explained by the following considerations. Compared to the Northwest European Continental shelf areas, the US regulations are less developed, in that they are more recent and have not yet demanded a high level of reporting, in the past leaving most of the decisions up to the operators, and allowing the offshore industry to "police" itself. Because of this the government does not have a large amount of information about the performance of structures, excepting information gained through special situations, such as accidents or from the sparse amounts of information supplied by the operators. The current situation for the USGS in the area of structural integrity, includes the problem of establishing a data base for many reasons, among them information on the environment, not only for frontier areas which require increasingly larger data gathering programs, but also for data on existing structures.

The amount of data required for the USGS to determine the safety of a structure is dependent on what the relative safety requirements are used. For example, the conditions which are imposed on the regulator will vary according to the contemporary demands. In the US these have been increased by the recent Outer Continental Lands Acts Amendments, which generally require more strict regulation of OCS activities. A pressure like this will influence the amount of data necessary for the regulator to obtain. How much substance there is behind these requirements is doubtful, and of course cannot be determined, since the regulations will require approximations. A good indication of the degree to which the regulations may vary for somewhat vague reasons is reflected in the statement of why the verification program itself is necessary for offshore structures.

"What a verification and inspection program does is provide the public with a practical way of providing credible assurance to the public and the various governments (at local, state, and national levels) that all reasonable precautions have been taken, based on the best applicable technical and environmental knowledge available, to ensure the integrity of the offshore structures".[8]

In practice an inspection program will only be an approximation of what is needed for the specific regulator's needs, and as such the regulator will produce a balance between production needs, environmental needs, and safety standards. Other factors will also be included in the more general appraisal of a group like the Marine Board which takes into account the variety of conditions to which the regulator must respond, such as the types of environmental phenomena which will be experienced, the types of structures encountered, and the way they are manned, which together require a different standard of inspection for safety.[9]

In practice the inspection standards will not always focus on long run inspection needs, since short run needs will vary.

A recent experience DnV has had with its certification requirements, demonstrates this situation for underwater structural inspections, where "the pressure has come from the universities and research institutions and may have caused a certain overaction with regard to fatigue in tubular joints." A possible future reduction in the amount of detailed node inspections required by DnV has been indicated. "The reason for reducing the requirement to magnetic particle inspection (MPI) of such joints on structures of North Sea standard, is that both operating experience and laboratory test results indicate that this can be done. Without the magnetic particle testing performed on these joints in the past five years, this conclusion would have been impossible to reach."[10]

The purpose of this discussion is to illustrate the variety of data needs, and their dynamic nature, based on local conditions, etc.

For many of the US OCS areas which are frontier areas, such as the Artic, the North Atlantic, the deeper Gulf of Mexico regimes, and the West Coast areas, similar large amounts of data may be necessary. The need for underwater access will be a function of the data requirements.

6.3.2 Current and Future US OCS Regulatory Requirements for Inspection

The USGS has not yet required the underwater inspection of structures on a prescribed basis during the platform operating period, (after installation is completed). During 1980, formal announcement of proposed rules for underwater inspection of OCS structures will be made by the USGS.[11] This will be the logical extension of the recently implemented (Jan. 1, 1980) OCS Platform Verification Program. Assuming that the USGS will follow the advise of the advisory report of the Marine Board COET, these rules should cover at least the inspection needs for platforms and risers. If they are in line with the Board's recommendations, they would be comprised of the following categories of inspections:

"1. Annual, visual inspection of the splash zone and above-water parts of the platform, supplemented by additional inspection after it has been exposed to, say, a severe storm or an accident.
2. General visual inspection by divers or remote TV of the submerged part of the platform and the contiguous ocean bottom when needed.
3. Visual inspection by divers or remote TV of specific, cleaned regions of suspected damage to the submerged part of the platform, possibly supplemented by non-destructive testing.
4. Periodic inspection of a cleaned, preselected number of joints of the submerged structure, supplemented by nondestructive testing if this is judged necessary."[12]

The first category is both periodic and event triggered, however this category applies only to above the water inspection. The use of the second type of inspection is qualified, i.e. "Category 2 inspections are made by divers or remote TV (i) if the Category 1 inspection indicate possible damage to the submerged structure; (ii) if available environmental information is deficient or if there has been an extension of technology for which there is little related experience; (iii) after an accident that may possibly have damaged the underwater portion of the structure; and (iv) to detect scour or bottom erosion."[13] Case (i) is of course event triggered, and cases (ii), (iii), and (iv) are triggered by the platform verification program's "check" points during the initial design, construction, installation phases, i.e. "from questions raised in the verification process. In such instance, Category 2 inspection should be made at least twice, with an interval of about five years between each inspection."[14] Category 2 inspection requirements as laid out by this recommendation do not include cleaning, and correspond roughly with a look for excessive growth (fouling) and checks for gross damage.

The Category 3 inspections are event triggered by discovery of problem areas during the Category 2 inspections. These call for cleaning beforehand "in order to determine the nature and extent of repairs or to resolve any questions raised by the previous Category 2 inspection. Information such as crack length, propagation rate, or crack termination may be essential to make a decision on repair and should be collected. To facilitate the examination, nondestructive testing may be added as appropriate."[15]

The committee's actual recommendations include the following use of the above categories:

"Adopt and implement an inspection program, including monitoring of the corrosion protection system and using the concept of inspection categories 1, 2, and 3, for platforms. The program should include the basis for determining events that precipitate Category 2 and 3 inspections."[16]

The COET also recommended the following limitations on the usage of these steps:

"Require that inspection plans be specific to the site, the platform design, and the installation history of the platform. While such plans should cover the newer oil and gas production areas such as the OCS of the North Atlantic and off Southern California, as well as the Gulf of Alaska, simplified procedures should be put into effect for the Gulf of Mexico."[17]

Although these guidelines appear to be quite lax compared to similar situations found in other countries, they are possibly adequate for an area like the Gulf of Mexico. However they certainly have not included any potentially extra work!

The basis for inspection in situations where corrosion protection monitoring has not turned up any deficiencies would be suspected damages due to storms, collision, seismic activities. These recommendations for regulations represent an attitude that if nothing unusual has happened to the structure and that if it is a conventional design, then no more detailed inspection beyond the above water visual inspection are needed. When Category 2 inspections are required, for the above stated triggering events, the inspection would be made only twice, and "Continued inspection should be contigent upon review by the government establishing the need for prolonged observation."[18]

The committee's recommendations for structures does not include the requirement for Category 4 inspection, based in part on the following arguments: "This inspection procedure is responsive to British and

Norwegian practices and requirements for construction and inspection of offshore oil and gas platforms in the North Sea. The committee questions the value of the additional data to be derived from this inspection in view of the costs for the large number of divers and services required to perform it, the limitations on the ability to conduct the inspection caused by adverse weather, and the certainty of data based on a limited capability to examine the part and its properties under adequate scientific and technical conditions. An application for Category 4 inspection could arise, however, if new environmental or technical information led to identifying a possible deficiency in specific joints of a platform."[19]

Similar in degree of inspection are the recommendations given for the riser inspections. These consist of visual inspections above the water and in the splash zone, supplemented with underwater visual inspection concurrent with the structural inspections, thus apparently on the same frequency required for the structural inspections. "If necessary, supplemental inspection for internal corrosion or erosion may be required. Cathodic protection measurements are necessary at least on an annual basis." is also included in line with North Sea practice.[20]

The Marine Board has included some consideration of the present technological capabilities, as reflected by the costs they associate with it. Their recommendations also reflect the general understanding in the US offshore community, that the general expertise gained over the last thirty years of offshore structures-related activities is adequate for establishing design criteria for relatively predictable situations.

6.4 Current Technology for Inspection

6.4.1 Role of the ROVs

The question of whether or not the ROV technology has any input value for the inspection and related regulations is not yet fully determined, since the regulations have not yet been made, and also the role is not clear from the Marine Board's recommendations.

The Marine Board has indicated that the present day technical capability for performind NDT on the North Sea has been limited "by the lack of quality control standards in application. Instrument calibration to repeatable standards, and personnel qualifications are key issues, along with recording and audit techniques for the inspection procedure."[21] A marked lack of underwater NDT capability is not so easily established in light of recent reports of adequacy of ultrasonic and MPI NDT techniques, at the least when carried out by divers. Still the repeatability of results has been called into question and may be a valid point. The ability to perform these techniques, under present system availabilities and capabilities is really limited to the use of divers. It does seem however that even if most US structures are in relatively shallow waters, the Marine Board does not require the use of divers, citing this as too costly, even when the capabilities of "viewing only" ROVs are considered adequate for most visual inspections. The report cites the inability of the non-diver systems to perform the cleaning required for the Category 2 inspections. This is also indicated in the Marine Board assessment of the capabilities as shown in Figure 4.6. Neglecting the references to untethered vehicles, in Fig. 4.6, we see that the use of vehicles (unmanned) for cleaning of joints is indicated to be R&D status at the time of the Marine Board review. This task ability is in fact available on at least two vehicles, as reported during 1979 (after the Marine Board report was completed), and may possibly be offered on more than two vehicles, being an extremely simple arrangement. Similarly the Marine Board does not account for the use of ultra-sonic thickness measurements from non-diver modes, except as state of the art, which is supposed to indicate that it exists but requires adaptation to the marine environment. In fact this has already occured for various ultrasonic (thickness only) measurement devices.

Unfortunately the changes in vehicles and sensor systems occur at a very high rate, being produced by numerous manufacturers with different sources of industry feedback. However, apparently the abilities are not satisfactory enough to rely on using them in the formulation of regulation guidelines.

A similar result has been reported for the use of NDT equipment by divers in a controlled experiment in shallow waters, where a trial carried out by Brown and Root cast severe doubts on whether current procedures and equipment can find and measure cracks in steel structures. This test in 20 feet of water had such devastating results that further testing was intended for evaluation of other systems.[22]

Based on these observations it may be safe to say that the Marine Board does not discriminate the use potentials of different delivery systems, but instead indicates that the areas needing improvements are first in the NDT apparatus. The Board notes that "the technology for inspection underwater is advancing rapidly and that most of the limitations that it identified are likely to be overcome in a few years."[23] The important issue to be raised is then whether or not these future increased capabilities would alter the need for inspection. Apparently not, since the inspection program that the Marine Board has recommended is not really dependent on any of the NDT techniques beyond visual inspection, minor cleaning, and cathodic protection monitoring, all notably within the state of the art for ROVs, if systems were deployed. The considerations of the Marine Board are limited to the restrictions that are caused by the inspection technology, rather than having established limits on the ROV potentials. Still the report indicates that as installations are being installed in deeper waters, there will be a work load of at least the cleaning requirements, for which the capabilities of ROVs and submersibles should be extended, along with visual inspection capabilities.

This appears to be the extent of the needs in ROV technology that the present inspection plans (for regulatory purposes) in the US areas will call for. Other needs will be in the areas of monitoring, needing the ability for emplacement of devices on structures and remove/replace them as necessary. This may in fact be within the current capabilities of many of the more sophisticated vehicles, providing that the design of the device incorporates some features to account for use of manipulators.

6.4.2 Future Demands for ROVs for Inspection/Regulatory Uses

The need for ROVs in response to the inspection for regulatory purposes in US areas appears to be slight for any activities beyond the proved observation capacity, along with some requirements for cleaning.

Still other developments have been cited by Busby as being necessary. This is mostly to do with the need for adaptation of the different underwater tools not only those used for inspection, but other types in addition to cleaning devices. According to Busby, "The greatest weakness at present is that nearly all underwater NDT devices are designed to be used by a diver. Consequently, the mechanical manipulators of the submersible and remote controlled vehicles, and the grasping terminations of atmospheric diving suits are at a distinct disadvantage. Other limitations include positioning, stability, maneuverability, and entanglement potential. No one vehicle or deployment capability is the ultimate substitute for the diver, each has its own peculiar advantages and disadvantages. One of the more promising capabilities for inspection and certain forms of testing is the remote controlled vehicle, but certain of its obvious deficiencies must be corrected before it can realize its full potential."[24]

We return to the original question of what is the role of ROV capabilities as an input to the inspection regulations. They appear to be very far behind any consideration of the role of inspection itself, neglecting the mode of access utilized. As stated in Section 3.2.5.1, the opinion of some offshore operators is that the inspection results (which are really only a guide to the needs for remedial work) are not used by operators for planning purposes. As such they will only represent an added cost. A similar view was given to the Marine Board by an industry representative who stated that, "The most important consideration by far in achieving safe and reliable long-term operations in the offshore environment is proper design and construction of platform and facilities. The experienced offshore operator knows that he cannot rely on in-place inspections to assure structural integrity."[25]

So, for the US at least, the role of the ROV technology would hopefully be a small one (if operators make good designs). The USGS Verification Program is more representative of an approach based on prevention by adequate design evaluations, fabrication, and installation monitoring, rather than by a reliance (of any degree of importance) on post installation inspection techniques, beyond of course visual inspection for damages, etc.

For frontier areas and newly introduced design applications the inspection needs will possibly increase, including some NDT if non-conventional nodes, for example, are used. The conventional steel jacket configurations do seem applicable to very deep applications (e.g. the Cognac and Hondo platforms) as long as environmental loads are not severe, as found in the North Sea. In fact the areas where the new designs would be utilized are in deeper waters with more hazardous environments, and thus new loading regimes. These factors may combine to force inspections to be carried out more often, and more thoroughly. By being candidate areas for these needs they would more than likely be areas with additional motivations for use of non-diver means, such as submersibles and ROVs, due to remoteness, and other operational factors as discussed in previous sections.

On the other hand new areas will be subject to more and better advanced environmental studies, creating a better understanding of what structural standards are necessary, etc. So it is not clear whether the form which the Marine Board has described for future regulations will produce any significant amounts of need for underwater inspection tasks, beyond the observation mode.

6.5 Summary

In response to the perceived public concern and demands for more careful control and administration of safety on the OCS the USGS will be issuing proposed rules for underwater inspection of structures and pipelines. The recommendations provided by the Marine Board call for minimal inspection efforts in line with the industry view that adequate design will provide for adequate safety.

The need still will exist for greater data gathering efforts for frontier areas or designs. The data is needed for evaluation of current structures and for developing new requirements for future performance criteria.

From these considerations the primary function of the ROV technology will be to provide efficient and cost effective underwater delivery systems. Due to the current state of the art, the regulations should not rely heavily on the use of access other than divers, due to lack of adequate capabilities to perform inspection-related testing. This shortcoming is due to the NDT equipment available and to the vehicle systems available, and in sum appears to have not promised enough capability to alter the offshore operators' general approach, which includes minimizing the need for underwater intervention.

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11. Telephone conversation with Richard Giangerelli, USGS Conservation Division, January 1980.

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7. DEVELOPMENT OF ROVs

7.1 Perspectives on Undersea Teleoperator Development

Specific ROV development programs have been reviewed by the National Oceanic and Atmosperic Administration Office of Ocean Engineering (OOE), and their work provides details on all the current major programs.[1]

The interest here is to identify the programs and their relation to the issues which have been included in this assessment. These include the cost, safety, and utilization considerations for undersea teleoperators, and specifically for the different ROVs.

The development of the ROV systems may be considered at two distinct levels. The first level focuses on performance criteria and the needs for actual hardware improvements. This may be approached from two views. The first view is to consider the developments occurring in specific sub-systems, e.g. the improvements in the available navigation systems, positioning, or station keeping sub-systems. The second view is concerned with general technical developments, especially the use of microprocessors on the vehicle package, allowing for improvements in control capabilities, telemetry systems, and other synergistic aspects of the system.

The second major level of development focuses on the functional orientations of the systems. This is a result of the increased usage of systems, calling for more specialized systems in response to the different user needs, especially for deep water oil and gas production. This produces very specific development orientations, which are reviewed.

After considering the above aspects of ROV system development, the involvement of different government organizations in development is examined. The high risk or long-term development programs are primarily government funded, as they have been in the past. The intent here is to identify the orientation of these programs to determine how well they are related to the various users' problems, whether cost related or performance related.

7.2 Performance Criteria and Sub-System Improvements

Sub-Systems

In general the ROVs of the bottom crawling and free-swimming types, are composed of the following general sub-systems. The sub-system include:

Surface/Shipboard Elements

- power supply, and conditioning equipment
- surface vehicle and cable handling equipment (winches, crane, davits)
- control station (data handling, controls, display, and navigation components, along with navigation system transducers)
- umbilical system if used

Vehicle Elements

- umbilical system termination
- control and electronics equipment
- power distribution equipment
- structural components
- propulsion system units (hydraulic source, electrics, thrusters, pumps, etc.)
- navigation system equipment (pingers or transponders)
- sensor systems (cameras, probes, accoustic equipment, compass, etc.)
- actuators (manipulators, emergency cable cutter, cleaning jet, etc.)

- ballasting system
- telemetry system

Umbilical System

- strength member
- power and signal transmission elements
- launcher or depressor clumps
- buoyancy members or flotation devices

Operators of free-swimming ROVs have indicated the following operating problems, in the order of frequency of complaints.[2]

Problem	Number of operators
Entanglement of umbilical	18
Electrical connectors	12
Sediment/visibility	11
Cable rupture by abrasion	10
Electrical interference in cable	8
Support ship station keeping	6
Compass effected by structure	6
Ship power supply surge effects	5
Currents excessive	5
Sea state excessive	5
Others; including inadequate payload, inadequate manipulation	2 or less

This information does not provide a general performance indication, since it represents problem areas within the existing equipment capabilities rather than overall equipment short-comings, such as lack of more efficient manipulator control configurations.

Offshore installation managers offer other aspects of the ROV systems as deficiencies. These include lack of payload, lack of reliability (in general), and lack of more complex task capability.

The vehicle deficiencies listed above are, problems which will be corrected by experiences learned from increased usage or refinement of sub-system components. The deficiencies cited by offshore installation managers are a more difficult set of problems to respond to. These require new or different system designs and refinements.

One sub-system problem is vehicle entanglement. In some cases this is due to the debris in the area of thrusters, but more generally it is due to the problems associated with the umbilical. The umbilical is both desirable and at the same time a drawback to most of the ROVs. Many of the functional features of the ROVs are due to the umbilical, primary ones being unlimited power availability for short term levels and for long mission durations needs. The tether or umbilical cable allows high information rate transmission, real-time surface vehicle interaction, and an emergency retrieval capability. One of the emerging splits in ROV systems is the development efforts for systems which do not require a tether, versus the tethered design.

Some general effects of eliminating the tether are clear. It requires: the development of through the water communication systems, of which there are not any plausible without severe data rate limitations; limitations on power levels and mission durations; and probable loss of real-time visual information (due to data rate restrictions). Many of the ROVs in use today are totally reliant on visual input for navigation and positioning of the vehicle. The loss of this will require a large increase in the quality of other sensing data, to make up for the loss of such a valuable means of navigation aid. By ridding the vehicle of the tether, certain increases in maneuverability are gained. However, the cost of doing so is presently too high in terms of reductions in vehicle/surface control and data transmission. Capability for real-time observation or manipulation under any circumstances requires more interaction between the surface and the vehicle than any current tetherless system provides.

Operators of vehicles are working effectively with the tether restriction, using smaller umbilicals when possible. Near future commercial vehicles will be tethered and many sub-system improvements will be made for these types of vehicles. Detail on un-tethered system development is given in section 7.3.

Of the many significant areas of sub-system improvements, most are not relevant to the general questions of this assessment. Certain sub-systems such as that for navigation, are becoming increasingly sophisticated, with manufacturers offering off-the-shelf technology for ship and vehicle systems. Vehicle navigation systems, such as short baseline accoustic navigation systems, provide the potential to locate and track (with good precision) the true vehicle position in accordance with convenient coordinates, in real time. These allow for higher system productivity, along with providing engineering related information for pipeline routes, etc.

Other components such as the manipulation systems have been discussed previously. These areas require the implementation of known technology, from different industry sectors. Other equipment such as CCTV systems are gradually improving. Recently less expensive color CCTV systems have become available, but they are not yet widely used on ROVs, and whether they will provide increased capabilities is not readily apparent.

Microprocessor Use

Beyond improvements for the different sub-systems of an ROV are the steady pressures for more complex systems. Some ROVs are designed based on microprocessors, for control and telemetry system improvements. Since this is a development of major importance, some of the aspects of how the systems are improved merit discussion.

One area of use of microprocessors is to establish all command and data handling via a radio-frequency (RF) telemetry system, with digital signal transmission. This entails providing for analog/digital and a digital/analog interfaces on the surface and on the vehicle, and inputting all transmission needs through it. This allows for a smaller umbilical, using possibly one twisted pair with the power transmission line, a co-axial line, and strength member.

Although this may only require a specific multiplexing or encoding unit, this is the start of a system with more flexibility for modifications, when new sensor or actuator channel needs are imposed. This also helps to eliminate cross-talk in the cable, a major problem.

Development of data manipulating sub-systems for digital data transmission is also an important step in the direction of future utilization of optical fibers with or in place of umbilicals. Optical fibers may soon be used along with a strength member to provide a very small diameter umbilical. Another approach (currently under development testing by the Naval Ocean Systems Center) is to have a fiber optics communications link with the vehicle. The fiber optic link will be deployed from the vehicle as it swims through the water, causing virtually no drag. The use of fiber optics links will necessitate adequate information processing capability on the surface and on the vehicle.

Another area of use of microprocessors is to provide for closed loop vehicle control. Although it is not established how many vehicles use this or similar design approaches, it is possible to use a microprocessor-based control unit on the vehicle, and allow the vehicle to perform many automatic or closed loop functions, without interaction with surface controls unless the surface requires a change of status. This includes closed loop elevation and heading control, and in one case is used with an inertial heading correction capability.[3] This same source has indicated that the control of a vehicle's manipulator is more easily carried out by allowing the microprocessor on board to perform many of the necessary calculations (for manipilator joint configurations etc.), rather than requiring transmission to the surface. This allows for a less complex transmission system and a more reliable system.[4]

Other proposals for use of microprocessor based computing include general use on the surface for better displays, data analysis, etc. They may allow for supervisory control, simpler forms of which are now used, e.g. for the integrated thruster control needed for automatic heading capability.

The use of more sophisticated control systems and command/control data processing is being carried out on vehicles with tethers. These improvements will pay off in the long run, since the information processing and encoding will eventually be useful when the tether is not needed, so similar system experience is valuable.

In general there is a move towards more effort at the human engineering aspects of the surface control/operator interface. Vehicle operators have repeatedly cited the well trained or rather experienced pilot as a major element in a successful vehicle operation. The degree to which the operator control panels and control equipment may be improved is apparently limited, since most of the larger or more sophisticated systems have incorporated fairly good interface equipment. This includes adequate system monitoring information, and in some instances the use of overlays to depict the structure which the vehicle is working around.[5] These types of improvement are not technically limited since the available means exist, and it is only a matter of implementing novel or not so novel ideas, a process that is occurring in accordance to the widening use of ROVs.

In sum, the ROV sub-systems are slowly meeting the overall system demands. Clearly deficient subsystems are the manipulators and the the umbilicals. Alternately, the problems associated with the sub-systems used without an umbilical increase the operational difficulties. Increased use of local microprocessors will answer many of the problems.

7.3 Functional Divisions

Some general trends are identifiable among system development efforts. One of these is the fact that the ROV technology is maturing and the systems are more sophisticated than in the past. This is reflected in the degree of specialization needed to provide adequate capability for certain users, along with increasingly higher general levels of system capability found on most commercially successful systems. The specialization of systems is a way around costs which would limit the general capability of less specialized systems.

One specialized development is the un-tethered system. Although these are not yet commercial, they are presently being developed for either prototype purposes, or as test-bed systems. The first applications of un-tethered systems will be for scientific and research related uses, including oceanographic data gathering, since they will be power and control restricted to such a degree that manipulative or other power or information demanding activities will not be possible. Other users such as the military will be able to use an un-tethered vehicle for surveillance/reconnaissance activities. There are not many uses for such limited data gathering orientated capabilities in the offshore oil and gas field development activities.

The following discussion indicates some of the reported areas of development of functionally specific ROV systems. Other than the tethered/un-tethered distinctions, these systems are not readily identified except by the application intentions, or by the development situations. For deep water, the offshore oil and gas industry has shown an interest in ROVs, but with a very task specific approach, not in itself insisting on general free-swimming vehicles.

Functional System Descriptions

Some equipment is now being introduced which avoids the use or minimizes the use of manned intervention, and is built for specific tasks. Examples are the different flowline connection systems. Although these are task specific devices, they are designed to be diverless, and as such, could be considered teleoperators. Although they are not in wide use, they fullfill the requirements for carrying out an activity on a remote basis.[6]

General purpose ROVs are a second type of teleoperator, and are continuing to be developed for light manipulation and viewing work.

Construction orientated systems are now being proposed, although only a few have been carried through the design stages. Included among these could be the currently commercially available pipeline burial systems, such as the Kvaerner-Myrnes trenching system, already developed and tested.[7] Future systems will possibly include the pipeline tie-in systems. One under development by a consortium of oil companies is the DWPR, a Deep Water Pipeline Repair system. This concept includes a remotely operated submerged work platform, capable of deploying specially designed pipe-working tools with its two manipulators (each six DOF and force feed-back designs). Also capable of dredging operations, this system is designed for depths to 4,000 feet.[8] The current status for this system is unknown. A similar concept is the submerged pipeline repair system (SPRS), which has been designed to be able to perform an unmanned repair or connection of submarine pipelines in water depths to 1,500 feet in a North Sea environment.[9] It is sponsored by a group of oil interests. The current status of this system is not known, although it has apparently not been carried beyond model testing.

These two deep water pipeline related systems have been carried to the stage of concept development. A third concept, a maintenance orientated system has more recently been publicized, and is more advanced in terms of completion. This system is the EXXON TMV (Tethered Maintenance Vehicle). This vehicle is probably one of the few to truly eliminate the need for the diver for deeper operations. It can operate where there is no apparent potential for use of ambient divers, e.g. it is designed for water depths of up to 3,000 feet. It consists of a submersible unmanned TMV, a set of interchangeable tool packages used with the TMV, a launch and recovery system, and support/control packages. It will operate from a dedicated work boat, and will be based on sub-systems that allow extensions of the depth capability. The system is to be used for maintenance of EXXON developed deep water production system risers. It may be operated either as a free-swimming tethered system or, when used to transport loads in excess of 4,000 lbs, it may be suspended from a load bearing tether cable. The system will be used with dedicated tool packages. One tool package is for installing specially designed flowline swivels, replaceable (by design) by the TMV system. Another tool package is designed for hose replacement. A third took package is for general work such as cleaning and inspection, etc. The vehicle is still in a development stage, but advanced testing and prototype manipulation equipment has been manufactured.[10]

Other groups are also interested in specific function vehicles, such as the TROV vehicle which has been set-up by Intersub Development for survey of pipelines.[11] Although the vehicle system is not itself so specific, the sub-systems which are used are very task-orientated, and therefore this could be considered to be a specialized vehicle.

A diver assistance vehicle is now being proposed by NOAA, Office of Ocean Engineering. Their work is aimed at producing conceptual configurations of a Remotely Operated Diver Assist Vehicle (RODAV), which would be used in support of the NOAA scientifically orientated diving activities.[12]

A diver assistance system is also being developed by a European Economic Community project, conducted by Dragerwerk AG/ZF, Herion-System, Technik, aimed at increasing diver efficiency, and for use in support of divers by providing special services (electrical, hydraulic).[13]

An "inspection vehicle" project may be carried out in Norway over a five year period; details are not yet firm.

A distinct area of undersea teleoperator development includes the few but well developed maintenance systems for subsea production systems. The best known of these is EXXON's maintenance manipulator system (MMS). This is a purpose built manipulator used with a subsea production system's manifold template, either manned or unmanned, operated by being lowered on an umbilical, providing power and commands, and able to remotely replace any of the component packages used on the SPS. This system has been proven in shallow water tests. Although it is designed for 2,000 feet, a prototype system has been installed in 170 feet. It was developed with other remotely operated devices, as part of a 400 man-year, $66 million deep water production system development program.[14]

A similar remotely operated manipulator maintained well head system has been developed by a program initiated by ELF-AQUITAINE, and tested partially offshore of Gabon, again like the EXXON tests, in shallower water than the final system deployment depth.[15]

Finally there are the un-tethered vehicle system developers. Although of diverse backgrounds, in the US they are funded at least partially by the US Navy. Other groups such as the ANGUS/ROVER project at Heriot-Watt university are working with more general government funds, from the UK Science Research Council and the UK Department of Industry.

A single commercial developer expressed an interest in un-tethered vehicle development when contacted, and this was ISE (International Submarine Engineering Ltd., Canada). They have completed conceptual designs for the "autonomous remotely controlled vehicle ARCs."[16] The vehicle will have a final configuration based on the particular customer's needs, and will be built upon request.

Most of the un-tethered designs have been development orientated. One vehicle, the EPAULARD, has been produced in France by CNEXO and is a limited surface interactive vehicle, taking limited accoustically transmitted commands and operating on a semi-autonomous basis.[17] Other systems such as the MIT robot sub and the UARS have been robots in that they have not had an active surface interface, an area of current development.[18] These systems are specialized in that they have limited control and data transmission capacity and as such are orientated for deep ocean data gathering or other similar work.

An advanced un-tethered system development/evaluation project, the EAVE (Experimental Autonomous Vehicle Program), is being carried out for the USGS at the Naval Ocean Systems Center (San Diego) and at the University of New Hampshire. This work involves the development of EAVE EAST and EAVE WEST, two test bed vehicles designed to evaluate and help in development of un-tethered inspection vehicle technology, in support of the USGS OCS research program. The EAVE WEST is partially under USGS funding with other funding from Navy sources.[19] An important aspect of the EAVE WEST will be the incorporation of a manipulator, designed under NOSC independent exploratory development funds. It will be used to demonstrate supervisory controlled manipulation, linked to the surface through small bandwidth accoustic commands. Similar command transmission and control configurations will be requisite for future un-tethered vehicles with any capacity to perform tasks beyond observation or passive data collection.

Other vehicles sponsored by the Navy include a Naval Research Laboratory project, the UFSS (Unmanned Free Swimming Submersible) which is designed for deep water long range data gathering missions.[20]

The above system development areas represent the variety of more specialized systems. The sponsors of these developments have specific missions or tasks which require the ROV to be incorporating certain features which then require certain configurations, etc.

Although these functional categories do not completely define ROV and teleoperator development, they represent the current organized research and development.

Functional Divisions-Future Uses

The future users of the ROV technology will continue to have distinctions based on their interests in specific tasks. A major example of this is the deep ocean mining applications. So far the deep ocean mining (DOM) ventures have had to develop specific equipment for their purposes, in support of mine site evaluations and equipment testing. Conversations with equipment developers for some of the DOM ventures indicate that their needs are specialized, requiring an improvement in the available bottom survey equipment. They do not intend to use any second system intervention with the dredgehead or other types of mining devices, and envision bringing the whole system up to reasonable depths for any repairs, etc. DOM ventures have been, and still are, interested in ways of decreasing the cost of survey information, needed to optimize nodule mining activities, by identification of prime mining areas. Although to date they have used towed systems, they may at some time have some interest in an un-tethered system. They do not intend any capacity for repairs by manipulation or observation, since any mining equipment will have to be extremely reliable to begin with and will be adequately monitored by built-in systems.

A potential user of ROV technology is the Ocean Thermal Energy Conversion (OTEC) system. Although the tasks required are not yet clearly identifiable, they would be similar to the observation and inspection activities identified with the offshore oil and gas installation tasks. Although no specific references have been found to the use of ROV technology here, there has been an inclusion of manned submersible costs in the calculations for annual maintenance of OTEC facilities.

General Development Outlook

Deep water oil and gas production systems will be systems like the EXXON developed SPS, utilizing the MMS, and the TMV for support during installation and operation. They do not rely on general purpose vehicles. Oil companies are developing dedicated and proprietary systems of their own. For future deep water developments, the oil companies with the know-how and specialized equipment will be in a commercially advantageous position. These systems include manipulators with advanced control concepts and purpose designed tool sets. They are designed to work on components themselves intended to be accessed by the ROV. There is not yet a great volume of work in this area. The equipment is developed under oil company contracts (as opposed to entrepreneur ventures), by the submersible and related system manufacturers. The smaller, cheaper and less effective systems are more "venture" orientated, they do not compare in cost to these larger development projects. The oil companies do not do a large amount of diving, manned submersible, or ROV research for currently exploited depths in the offshore industry. The oil company development programs like the TMV do demonstrate that when the cost is justified, there is a way to take the man out of the underwater portion of the system. Notably the oil companies have not been involved in any publicized projects involving development or research in support of un-tethered vehicles.

The next section of this report is concerned with the government role in the development of ROV technology.

Government Involvement

Although the general undersea teleoperator technology is not limited to government oriented missions, the manned submersible and ROV technologies are based on government development programs primarily sponsored by the Navy.

In the US the most advance ROV systems have been developed for Navy use and have had spin-offs into the civilian commercial markets. This is true even today with the Navy providing almost all the funds for the research for the next generation of ROVs, the un-tethered systems. The most sophisticated ROV operating today is the Navy's RUWS, employing the most advanced launching, navigation, and manipulation systems. The US Navy has supplied the funding for the original development of KEVLAR, now widely used for umbilical strength member, as part of the overall $11 million RUWS development program.[21] The examples could go on and on, but the point is that until recently ROV development has been primarily a government activity.

In more recent periods of development, since 1977, there has been a surge of commercialization of the ROV systems, indicating the technology has come out on its own in commercial terms.

The question which now must be raised is how will the near future development and use be related to government involvement and support.

First, three agencies have current direct involvement in the technology. These are the various Department of Defense Navy users and laboratories, the Department of Interior USGS Conservation Division, and the Department of Commerce NOAA Office of Ocean Engineering (OOE). Peripheral federal interests include the OOE Manned Undersea Science and Technology program, and the OSHA and Coast Guard diving safety enforcement groups.

Among these users there is little money spent outside of the Navy's programs. Notably one of the major non-Navy funding sources for government sponsored ROV research is the USGS. Shrewdly, the programs funded by the USGS are administered by NOSC, allowing the USGS to get as much "mileage" as possible for their money.

The Federal policy for research and development for marine related technology is as follows, and applies to all situations where the government has extended its role into the technology development process beyond the usual frontier of what the private industry should be doing (with possible government assistance when needed). The government's role may be significant if:

> "... (1) in the case of disaggregated industries", ... "where the structure of the private sector sometimes discourages applied R&D because of lack of capital and expertise, or where the industry has no incentive to develop new information that would be available equally to competitors as well as sponsors of the research; (2) where the government is the consumer of the technology, e.g. defense systems, space technology, and undersea technology; and (3) in instances where support of long-range, high-risk, high-priority technology is clearly in the national interest..."[22]

The Navy's role has been to sponsor the development of the ROV technology for their own missions. The current development of the ROV technology has out-grown this pattern of Navy use, and the civilian sector, primarily the offshore oil industry, is the beneficiary. Other agency roles are the USGS's mission to develop long-range technological capabilities for offshore monitoring purposes.

The OOE is also active in ROV technology by fullfilling its role of providing for technology transfer assistance, and distribution of information concerning marine systems. Other than these involvements the Federal government has no present concerns with the ROV technology. The commercial development of the ROV will be the primary mechanism by which the ROV technology will become more widespread. For this reason there are doubts as to how fast the utilization of the ROV will take place, particularly in the shallow depths where there is a significant safety concern, as was discussed in section 5.

Clearly this leaves the growth of utilization of ROV technology in a situation where the economics of the system will determine the growth pattern.

Other countries face a somewhat similar situation. The exception to this is the UK. In the UK the development of the ROV technology, with potential for system improvements, is stimulated in two ways that are not among current US Federal mechanisms.

The first of these is the Offshore Supplies Office. This is a part of the UK Department of Energy, and was formed to stimulate the UK industry involvement in the supply of equipment and services to the offshore development taking place in the UK sector of the North Sea. Based on initially low estimates of the percentage of the market that would be directed to the British/Scottish industrial establishment, the UK Department of Energy established the OSO to help direct the UK research and manufacturing interests to increase the domestic captured market share. This has been somewhat successful, with approximately two thirds of the present expenditures for North Sea offshore development now going to the UK industries. This has been accomplished via research/development subsidies where a private venture group may apply for up to 50% funding from the OSO for a project that may have significant sales or manufacturing potentials for the offshore industrial sectors. Often a project may be the development of a product that originates in a different user sector and money is needed for a program to introduce it to the offshore market, as with the case of the different defense related technologies. Examples of this are inertial navigation systems, with potential future ROV applications, and the possible ROV utilization of accoustic imaging systems. Both of these are produced by defense contractors, who will not be able to introduce them to the commercial market without some financial assistance. The OSO allows for some assistance in cases with merit by operating a funding scheme through the UK Offshore Energy Technology Board (OETB). Details of current OSO funded ROV projects are not obtainable for obvious commercial advantage considerations, especially for more advanced systems. However, the past projects have included ROVs, primarily observation systems.

Another mechanism within the UK Department of Energy is an advisory group to the other divisions concerned with R and D, and especially R and D for underwater equipment. This group, the "Advisory Group on the Technological Developments Necessary for the Progressive Replacement of Man Underwater" (AGPRMU) was established within the framework of the OETB.[23] This group's general aim is to encourage research in automation underwater. It is composed of members of the underwater industry and other relevant branches of engineering, science, and the academic community. Although the effectiveness of this group and its actual activities are not yet reported on, the organizational espect of its having been formed at all is indicative of the potential role of ROVs, along with the UK "official" concern for safety offshore.

Although the US does not have any particular agency or department that would carry on similar activities, it is important that the OOE makes efforts to parallel the types of work that the AGPRMU would carry out.

If only commercial interests are involved, there will not be any cohesive program, even if it would only be an information processing situation, for fostering the use of ROVs in the US. This area of interest is within the scope of the OOEs responsibilities, and so far is being accomplished, evidenced by the agency's work in ROV related areas.

In general, the review of systems and developers does produce some questions concerning the US government involvement in near future ROV systems. As stated previously, there is now available ROV technology with adequate observation capabilities to satisfy most if not all of the diver "observation-only" tasks. At the same time there is a serious lag in the development of manipulation capability, since at least 90% of the system usage has been for "observation-only". The replacement of the diver in situations that are not of great commercial interest (as opposed to deep-water production systems EXXON would be interested in), requires cheaper and more effective manipulative capabilities. The present Navy oriented programs, including the USGS involvement, is directed at the next generation of systems, which entail even further difficulties in the areas of communication and manipulation. This advanced development is being carried out prior to the development of economical tethered systems. Due to an apparent lack of military interest in tethered equipment, especially for "less deep" application equipment, and the generally acceptable lack of need for other Federal agency involvement in development of technology for this type of system, it simply will be slow in coming to commercial feasibility. There are not any governmental responsibilities that would induce the government to stimulate the development.

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8. CONCLUSION

The users of undersea teleoperators are military, scientific, and industrial groups.

Military use of remotely operated systems in examined in section 2.2.5. This is a large area of use, for a broad range of applications, with some overlap with civilian application task content. The Navy has developed the most sophisticated undersea teleoperator systems in use today, and has been involved in the development of many sub-systems that are incorporated in the commercial ROVs and manned submersibles.

Use of undersea teleoperators by scientific groups is examined in section 2.2.4. Due to economic and operational restrictions, there is not widespread use of ROVs by this group. Instead it relies on divers, manned submersibles, or surface deployed devices. The exceptions to this are many of the towed ROVs and some of the early free-swimming ROVs which were developed by or for scientific users. Scientific groups are a potential future area of application of ROV systems.

The major commercial ROV developments have been by and in support of the offshore oil and gas industry. This industry has been working in continually deeper and more demanding waters, in many areas. The primary interest in refinement of underwater operations has been focused on activities on the Northwest European Continental Shelf. The underwater activities during the development of offshore fields are reviewed in section 3.

There are two major pressures on the offshore industry requiring the utilization of remotely operated systems. One is the cost of using ambient-pressure human divers. Although the diving industry is currently suffering from a cyclical down-turn in the service market, diving costs remain high in relation to other means of access, the ROV systems and manned submersibles. The second pressure is a general safety concern, in response to the risks associated with diving.

A large fraction of the underwater work necessary during the development of an offshore field has been identified as not particularly amenable to substitution of currently available ROVs in the place of ambient divers. This is true especially in the depths from 50 to 200 meters, where most of the current offshore development is taking place. At these depths the diver offers superior performance when compared to the ROV. This stems from a lack of ROVs with dexterous manipulative capacity, other than one system, the ROV ORCA, which offers master-slave force feedback manipulator control. This is the only ROV available on the commercial market with an advanced capability for manipulation, a necessity for ROV substitution for divers.

At the same time, for any depths over approximately 50 meters in the North Sea, there are major shifts that have been made to use of remotely operated observation systems. Most of these do not offer any degree of manipulative capacity. They are functioning at increasingly better levels of reliability. Possibly the offshore industry is giving more credibility to the ROV systems in general.

Still, the displacement of divers for practical work during many phases of the offshore development is not occuring. Some phases are more susceptable to ROV substitution than others. Table 3.5 summarizes the more general influences in the overall choice of alternative systems for underwater support during offshore activities.

By necessity, the diver is utilized for many activities in depth to

350 meters. At depths beyond this, potentially within the divers capacity to as deep as 450 meters, other means are used for accomplishing any tasks which have not yet been designed out of the activities, and require some kind of intervention. These means include manned bells with manipulators, free-swimming manned submersibles with manipulators, and one atmosphere diving suits (ADSs). In addition to these means offshore operators are now using new systems for the primary equipment in the deeper regions. Diverless and guide-wireless re-entry systems are used in drilling systems for depths to 1,400 meters, beyond the capabilities of any manned systems except the manned submersible.

On a depth basis exploratory drilling technology development is a few years ahead of production technology. Production systems have been designed and tested that do not require any manned intervention, serviced solely by remotely operated manipulator systems. The successful systems are proprietary and have been produced by the oil industry to ensure a capability for near future field development in depths to 500 meters. Once this capability is reached, the extension of the unmanned system to greater depths is not difficult. In summary, for the very deep areas, the industry is privately producing alternatives to suit the individual situations.

For less deep operations there is a more difficult problem in establishing capabilities. The ROV technology that is now available does not include many sophisticated vehicles when capabilities are in comparison to the diver. So far, the more capable (and complicated) systems have not been well received offshore. Only recently, over 1978 and 1979, have ROVs been discussed as having serious near future potentials for replacement of the diver for tasks more complicated than simple manipulation tasks.

Many of the more expensive and diver intensive operations, such as performing hyperbaric welds, are simply beyond the current and near future capabilities of remote systems. In cases such as these, where no method is available for allowing the designing out of the process, the ambient diver is used. Beyond the divers' depth range, no remotely operated systems are yet available. Some are under development. Other approaches are also being developed, relying on one atmosphere chambers. Until alternatives become available deep water field development will include the use of multiple small diameter lines and other partial solutions.

Of the operations that must be carried out, the one that offers the most plausible conversion to ROVs is the inspection of structures. The current volume of this work, examined in section 4.3.4, accounts for approximately 20% of the North Sea diver employment. This may be a future major application area for ROVs. This work is generally not on the critical path and does not entail the use of costly secondary equipment, and has low secondary costs.

A major emerging application for the ROVs is use in support of diving operations. Even when the diver is necessary, the difficult-to-manage secondary costs make any improvement in completion times very advantageous. A savings of half a day on an operation costing over $100,000/day will normally justify the cost of adding an ROV to the diving spread.

The cost and capabilities of the ROVs are examined in section 4. This has shown that the primary costs to do jobs which are within the "observation-only" limitation for vehicles are relatively less expensive for ROVs in deeper water situations as opposed to divers. Unfortunately, the offshore operator does not know in advance whether or not the job will be within the capability of the generally limited systems available. The secondary costs, such as the vessel day rates (for the primary task that the underwater operation supports, e.g. pile-driving), are so high that the operator may still be better off using a diver if possible. The use of very sophisticated ROVs does not offer a substantial saving for the short tasks in less than 150 meters depth, the approximate limit for non-saturation diving. In depth less than this, it is still probably more economical to use a diver. Before choosing the ROV, the operator may opt for use of other teleoperators, the manned bell with a manipulator, or the manned submersible, but the choice is task dependent and it is not possible to generalize.

The safety of the use of ROVs as opposed to divers has been examined in section 5. The major conclusions are that although the substitution of ROVs is occurring on a small scale for some of the divers non-observation work, the real safety gains will be due to increased restrictions on diving operations. In addition to an increase in the working diver's safety, regulatory requirements increase the cost of a diving operation, and the use of ROV becomes cost effective.

Cost data in section 4 indicate that for a sophisticated ROV to be utilized (when available) the capital costs could easily exceed the capital costs needed for a saturation diving system. ROV substitution provide only marginal saving after realistic contract costs are determined. Part of the problem is again due to primary work vessel costs, say for adequate crane capability for the job, rather than the ROV support ship needs. The result may be that the ROV does not offer large savings, but only offers a risk that the capabilities will be inadequate. This applies as well to less deep operations. Shallow water situations have an equally high risk to the ambient diver and unfortunately do not offer any apparent cost improvements by use of ROV unless extremely limited tasks are required.

The regulatory impacts of the availability of remote systems for performing inspections and monitoring roles have been examined in section 6. The conclusion is that the future US OCS area regulatory requirements for underwater inspections will be so minor that the ROVs will not play a major role in the assurance of offshore structural integrity. This is by design, since operators of production systems do not count on any form of reliable or effective underwater intervention, and design the structures accordingly. This effectively eliminates the need for detailed inspections in all areas but the most severe or where new unconventional platforms are used. In these particular cases, the ROV may offer a potential for obtaining information at a lower cost than by manned means; however, this is currently not possible due to the ineffectiveness of underwater non-destructive testing technologies.

In section 7 the development of ROVs has been analysed in terms of the specialization which is taking place in systems. This is due to the need for more expensive sub-systems for ROVs, to accomplish credible tasks. The cost of the supporting sub-systems requires vehicle specialization to allow for reasonable overall system costs. Although there will be some need for general vehicles with very advanced capabilities, there are currently no successful ROVs with this general high capability.

A major trend in vehicle research and development is the move toward un-tethered vehicles. This is difficult to justify if one assumes that it is best to exhaust the capabilities of the tethered systems first. The tethered systems have not yet reached an advanced stage. It is doubtfull if un-tethered systems have any near future potential for non-Navy or non-scientific uses due to the low level of the current tethered system capabilities, which may be degraded when the tether is removed.

The US federal government is not in the best position to make any improvements in the ROV systems. The Navy's missions require more advanced technology than the offshore industry. The systems enjoying successful commercialization are less than adequate for the offshore support needs. This has left a (hopefully temporary) gap in the overall utilization of ROVs. There is no Federal agency which has an interest in making the commercial use of ROVs more widespread. The Office of Ocean Engineering of NOAA, does handle marine system and hardware information and technology transfer for the federal government, and as such may use its activities to continue to promote the ROV potential, as it has been doing in the past.

With the developing commercial feasibilities of ROVs, combined with the recent high growth in the number of observation system vehicles available, the commercial development efforts may be able to produce an inexpensive system with adequate manipulative capabilities. This has not yet been the case. This is needed to augment or replace shallow water divers, a previously neglected safety problem. We should soon see a second wave of manipulator equipped ROV system utilization, following the first wave of remote camera systems.

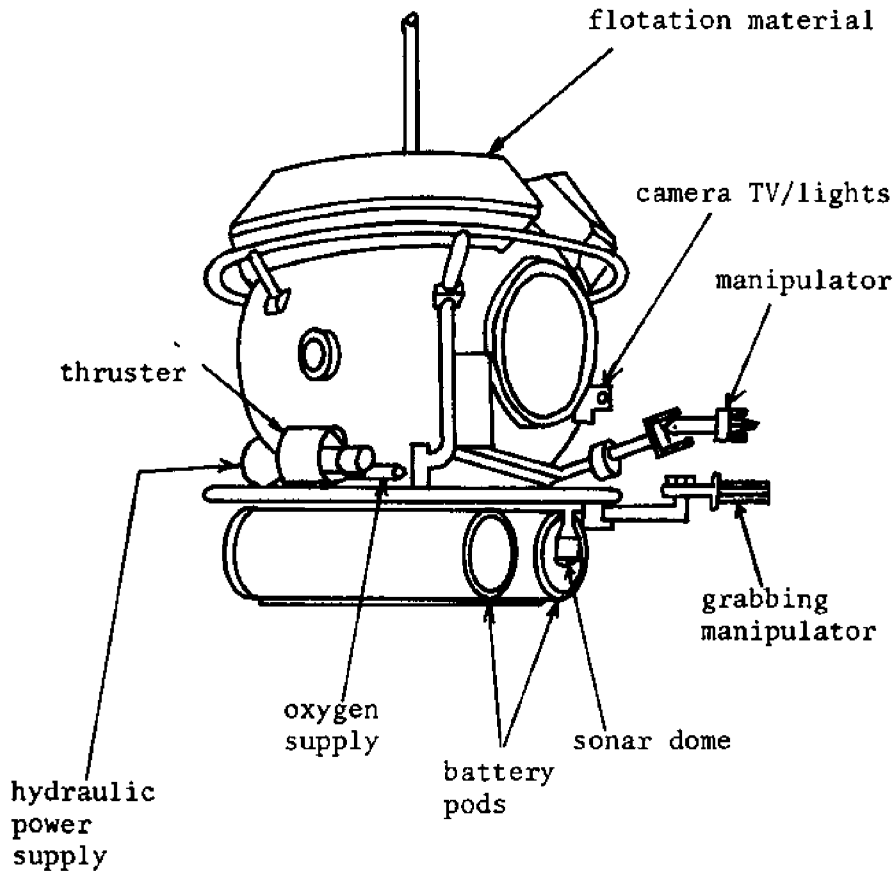


FIGURE A.1 MOBILE DIVING UNIT

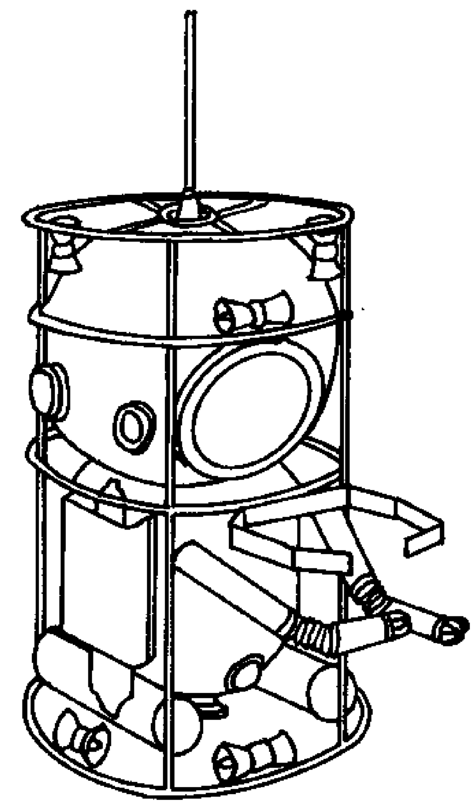


FIGURE A.2 MOBILE DIVING UNIT WITH DIVER LOCKOUT CAPABILITY

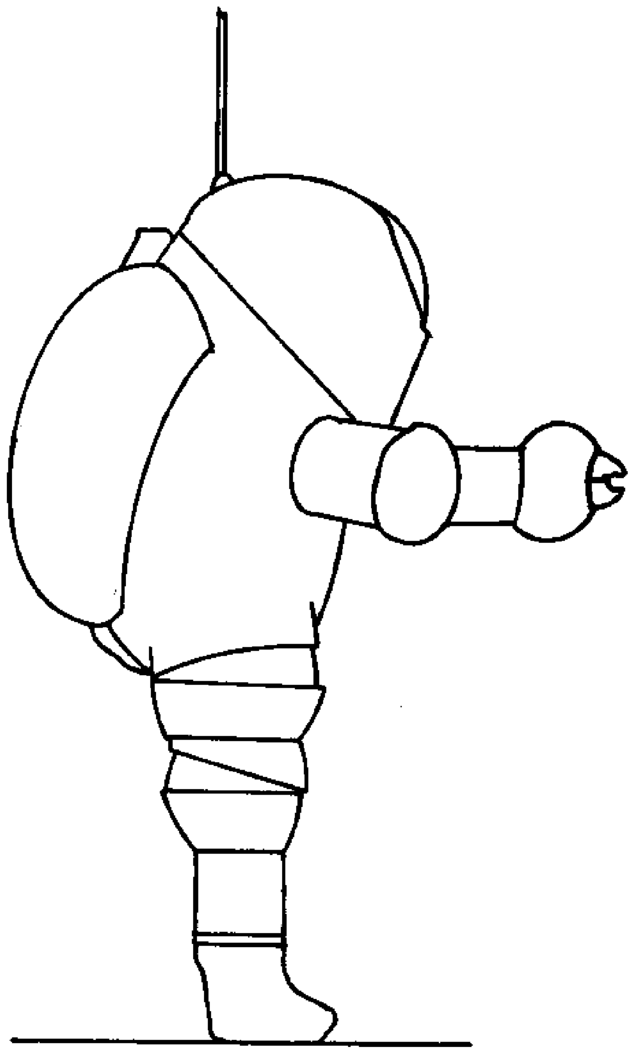


FIGURE A.3 ANTHROPOMORPHIC ATMOSPHERIC DIVING SUIT (ADS) (TYPE III - "SAM")

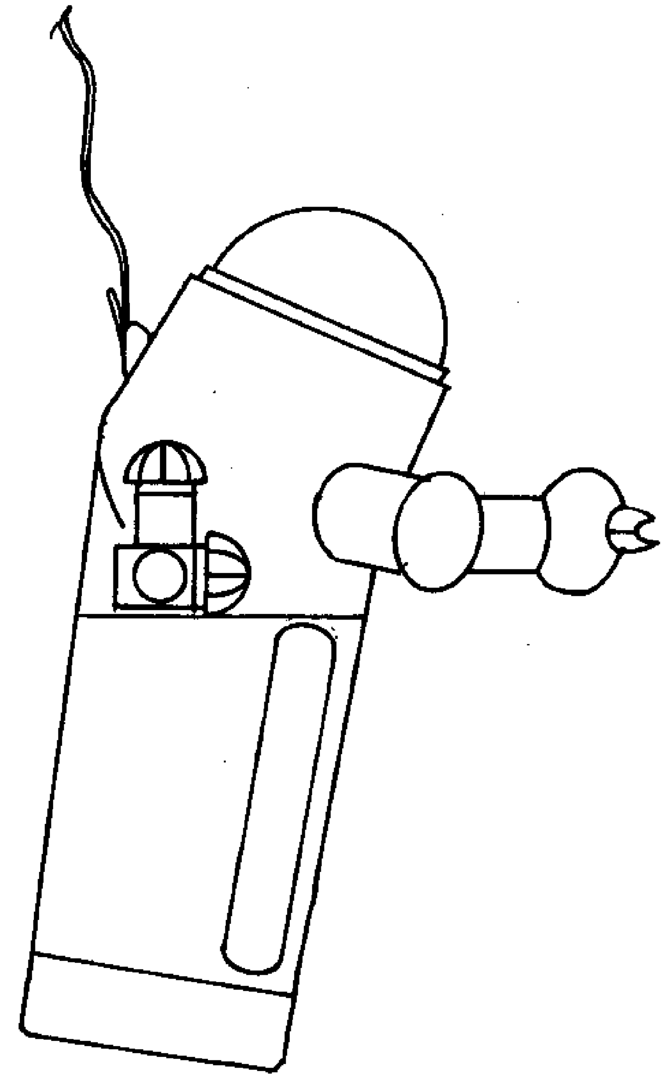


FIGURE A.4 SEMI-ANTHROPOMORPHIC ADS ("WASP")

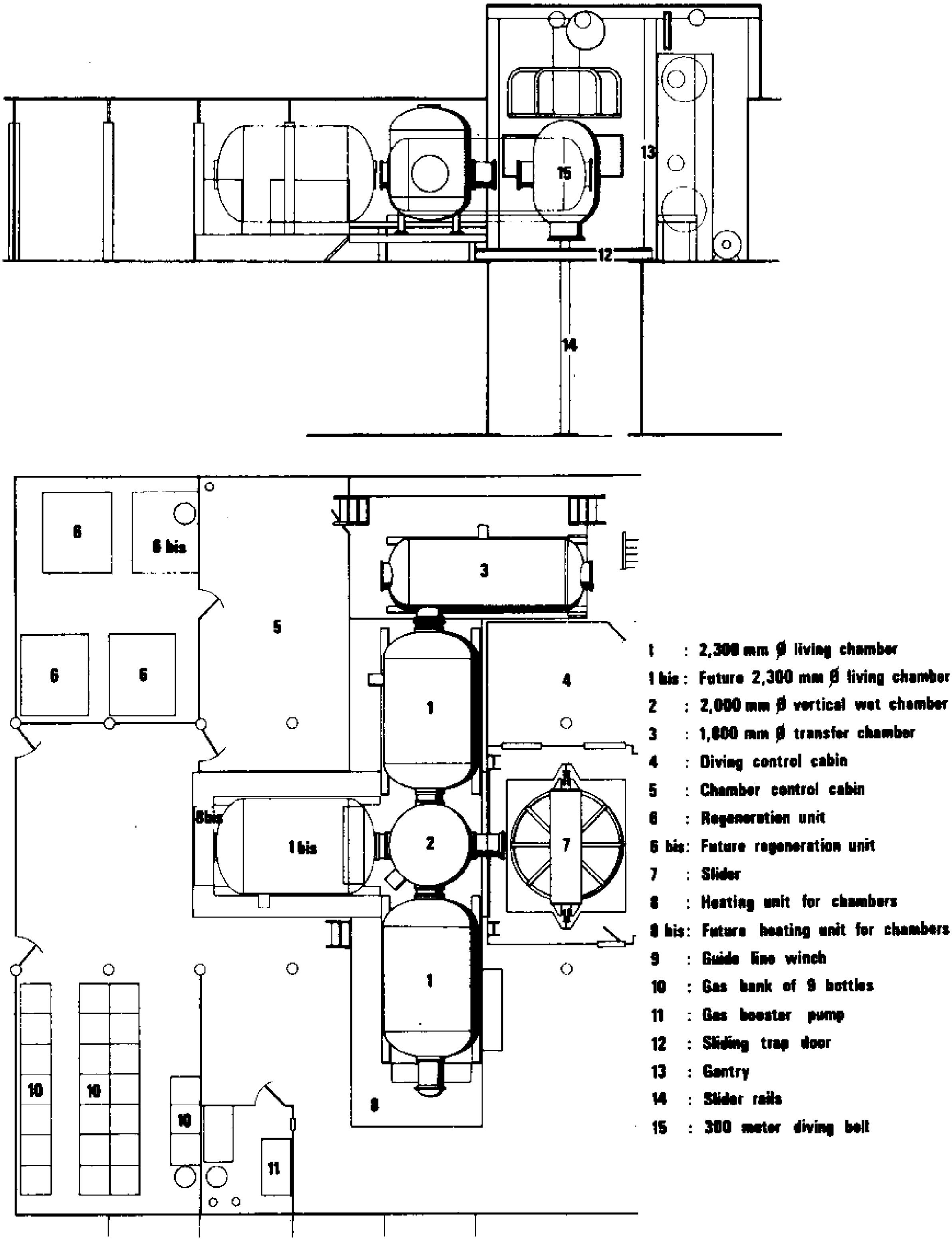


FIGURE A.5 SATURATION DIVING SPREAD - 8 DIVER CAPACITY AS INSTALLED ON TALISMAN.

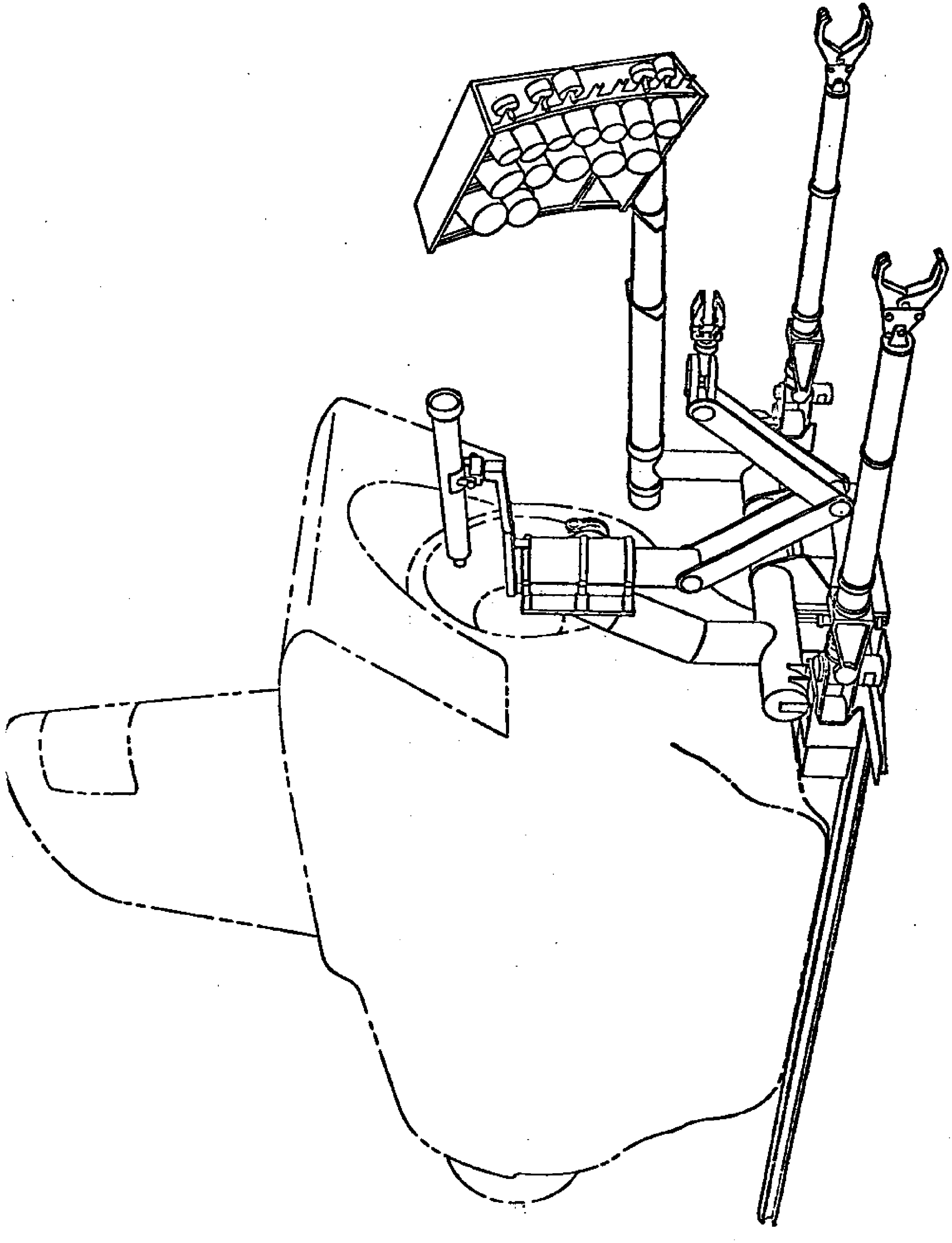
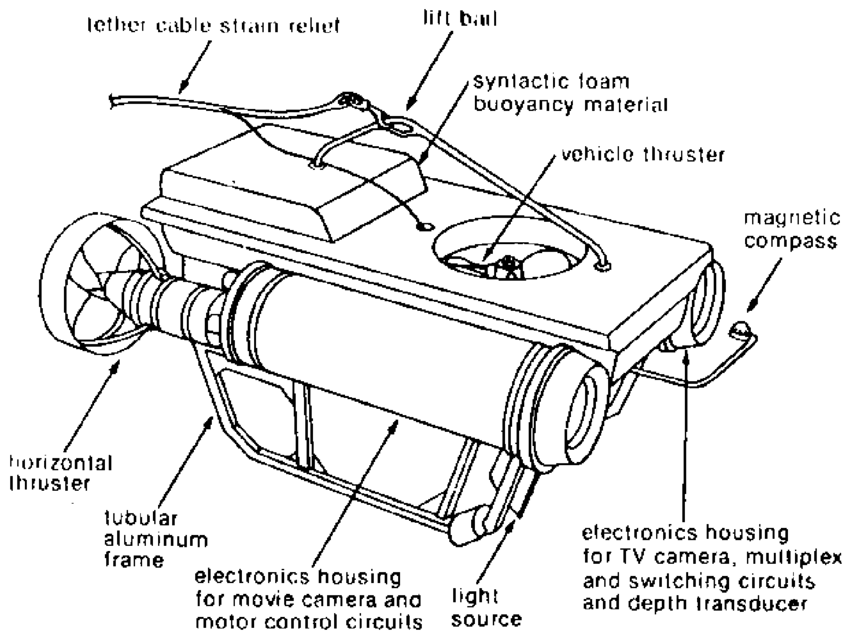
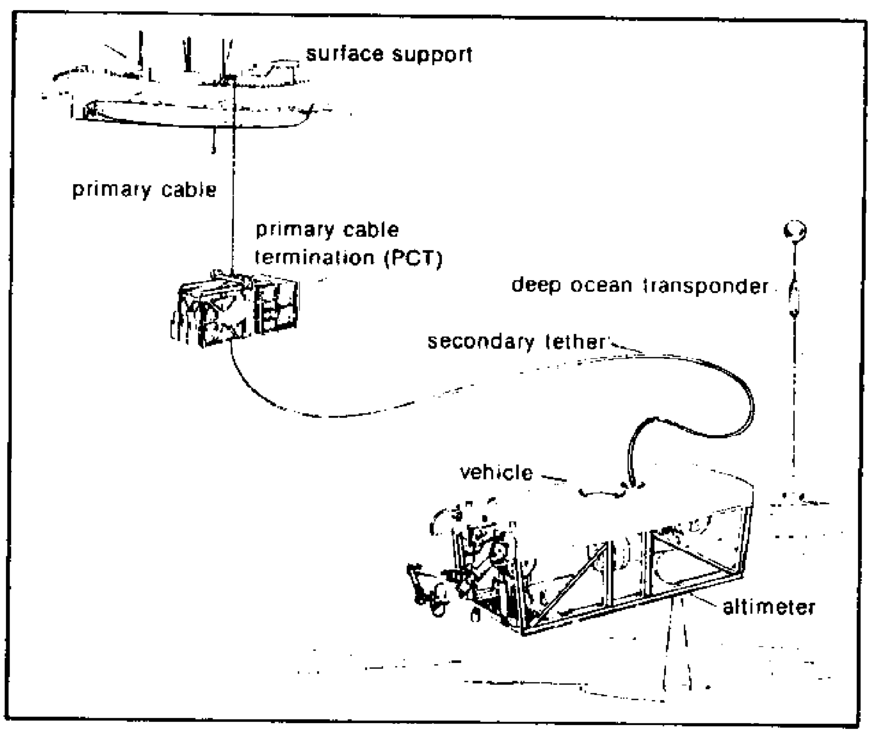


FIGURE A.6 WORK SYSTEMS PACKAGE (WSP) ON ALVIN



Components of *Electric Snoopy.*



Remote Unmanned Work System (RUWS).

FIGURE A.7 FREE-SWIMMING ROVs - ELECTRIC SNOOPY AND RUWS.

APPENDIX B

TABLE B.1 - CONTEMPORARY MANNED SUBMERSIBLES
(Operational in 1978 unless noted)

Name	Operating depth (m)	Operator
Supersub I***	300	Superpesa Transportes Maritimo Ltda.
Aquarius I	335	Hyco Subsea
Auguste Piccard	610	Horton Maritime Exploration
Constructor***	488	Deep Diving System Ltd.
Pisces IV	2,012	Dept. of Environment,Victoria B.C.
Pisces V	2,012	Hyco Subsea Inc.
Pisces VI	2,012	Hyco Subsea
Sea Otter	457	Can-Dive Services, Ltd.
Taurus*	610	Vickers Oceanic Ltd. (a)
Cyana	3,000	CNEXO
Globule	200	COMEX
Griffon	600	French Navy
Moana I, III	400	COMEX
Mob 501**	500	COMEX Industries
Mob 1001** & 1002**	1,000	COMEX Services
Mob 1003**	1,000	COMEX Services
Mob 1004**	1,000	N/A (a)
Neree***	200	Marseille
PC-8B	244	Intersub
PC-1201	305	Intersub
PC-1202*	305	Intersub
PC-1203	305	Intersub
PC-1204, 1205	366	Intersub
PC-16*	914	Intersub
PC-1801*, 1802*, 1804*	305	Intersub
Shelf Diver*	244	French Navy
S.M.I.*	300	French Navy (a)
PC5-C	366	Sub Sea Oil Services (b)
PS-2	312	Sub Sea Oil Services
Hakuyo	300	Ocean Systems Japan
Tankai	200	Fuyo Ocean Dev. Co. (c)
DSV-2K	2,000	Japan Mar. Sci.&Tech. Ctr. (a)
Skadoc 1000	330	Skodoc Submersible System
Urf	460	Royal Swedish Navy (d)
PX-28	500	Found. for Study and Protection of Seas and Lakes (a)
Jim (12 ea.)***	457	Oceaneering Int. (a)
Leo	610	P&O Subsea (a)
Mantis*****	610	Offshore Submersible Ltd. (a)
Mermaid III* & IV*	260	P&O Subsea
Pisces II	732	Vickers Oceanics Ltd.

Table B.1 (cont'd)

Name	Operating depth (m)	Operator
Pisces III	914	Vickers Oceanics
Pisces VIII & X	1,000	Vickers Oceanics
T-1	914	Vickers Oceanics
Vol-L1*	366	Vickers Oceanics
Vol-L2,L3,L4*,L5*	366	Vickers Oceanics, Ltd.
Wasp*** **	610	Offshore Sub. Ltd.
Alvin	3,658	WHOI
Arms**	914	Oceaneering Int.
Asherah	182	New England Ocean Services (b)
Beaver*	823	Int. Underwater Contr. (b)
Deep Quest	2,438	Lockheed Ocean Lab.
Diaphus	366	Martech Int.
Johnson-Sea-Link I*&II*	914	Harbor Branch Found.
Johnson-Sea-Link III	762	Harbor Branch Found. (a)
Marfab	N/A	Marfab Inc. (a)
Mermaid II	366	Int. Underwater Contr.
Mystic & Avalon	1,524	U.S. Navy
Nekton A, B & C	305	General Oceanographics
Nr-1	N/A	U.S. Navy
Opsub**	305	Ocean Systems
PC-14C-2	183	Kentron, Hawaii
Pioneer I	366	Seahawk Oceanics (a)
Sea Cliff	1,981	U.S. Navy
Sea Explorer	183	Sea-Line, Inc. (c)
Sea Ranger	183	Verne Engineering Inc. (c)
Snooper	305	Undersea Graphics, Inc.
Star II	366	Deepwater Explorations, Ltd.
Trieste II	6,096	U.S. Navy
Turtle	1,981	U.S. Navy
Argus	600	Institute of Oceanology,Gelundzhik
Atlanta**	100	Atlantic Research Inst. of Fisheries
OSA-3	600	Ministry of Fisheries, Moscow
Pisces VII & XI	2,012	Institute of Oceanology,Gelundzhik
Sever 2	2,000	Ministry of Fisheries, Moscow (c)
Tetis**	200	Ministry of Fisheries, Moscow
Tinro 2	400	Central Res. Inst. of Fish, Moscow
Mermaid IV* & V*	300	Bruker-Physik AG (a)

* Lockout
** Tethered
*** One-man vehicle
**** Tethered, one-atmospheric bell

(a) Construction
(b) Refit
(c) Inactive
(d) Sea trials

Source: R.F. Busby, Review of Manned Submersibles: Design, Operations, Safety and Instrumentation, (Oceanographer of the Navy, 1978) pp 8-14.

APPENDIX C

DATA ON REMOTELY OPERATED VEHICLES

Source: R. Frank Busby, Remotely Operated Vehicles, Sponsored by US Department of Commerce, Contract No. 03-78-603 (US Government Printing Office, Washington DC, August 1979) , pp 2, 19-23, 29.

TABLE
REMOTELY OPERATED VEHICLES DEPTH CAPABILITIES, MANUFACTURER AND OPERATOR BY CATEGORY

TETHERED, FREE-SWIMMING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS 002	984/300	Heriot-Watt University	Same
ANGUS 003	1,000/305	Heriot-Watt University	Same
BOCTOPUS	2,170/661	British Oxygen Co., Ltd.	Same
CETUS	1,500/457	ULS Marine Ltd.	Same
CONSUB 1	2,000/610	Institute of Geological Sciences	British Aircraft Corp.
CONSUB 201	2,000/610	British Aircraft Corp.	Sub Sea Surveys Ltd.
CONSUB 202	2,000/610	British Aircraft Corp.	Same
CORD I	1,500/457	Harbor Branch Foundation	Same
CURV II	2,500/762	Naval Ocean Systems Center	Same
CURV II	2,500/762	Naval Ocean Systems Center	Naval Torpedo Station
CURV III	10,000/3,048	Naval Ocean Systems Center	Same
DART	1,200/366	International Submarine Engineering Ltd.	Same
DEEP DRONE	2,000/610	Supervisor of Salvage (USN)	Ametek Straza
ERIC II	19,685/6,000	C.E.R.T.S.M.	French Navy
ERIC 10	1,640/500	C.E.R.T.S.M.	French Navy
EV 1	1,500/457	Kraft Tank Co.	Same
FILIPPO	984/300	Gay Underwater Products	Same
FILIPPO	984/300	Gay Underwater Products	Nereides, Orsay, France
FILIPPO	984/300	Gay Underwater Products	Uncommitted
IZE	1,640/500	Sub Sea Surveys Ltd.	Same
MANTA 1.5	4,921/1,500	Institute of Oceanology USSR	Same
MURS-100	329/100	Mitsui Ocean Development and Engineering Co.	Same
MURS-300	984/100	Mitsui Ocean Development and Engineering Co.	Same
OBSERVER DL1	600/183	C. G. Doris	Same
OBSERVER III	984/300	C. G. Doris	Same
ORCA I	2,297/700	Saab-Scania	Oceaneering International
PAP 104	328/100	Society ECA	Various Nato Navies
PHOCAS II	1,000/305	Geologinen Tutkimuslaitos	Same
PINGUIN A1	330/100	VFW Fokker	Same
PINGUIN B6	6,500/1,981	VFW Fokker	Same
RCV-150	6,000/1,829	Hydro Products	Martech International
*RCV-225	6,600/2,012	Hydro Products	Seaway Diving
RCV-225	6,600/2,012	Hydro Products	Martech International
RCV-225	6,600/2,012	Hydro Products	SESAM
RCV-225	6,600/2,012	Hydro Products	Esso Australia Ltd
RCV-225	6,600/2,012	Hydro Products	Taylor Diving and Salvage
RCV-225	6,600/2,012	Hydro Products	Wharton Williams
RCV-225	6,600/2,012	Hydro Products	Oceaneering International
RCV-225	6,600/2,012	Hydro Products	Japanese Navy
RCV-225	6,600/2,012	Hydro Products	Same
RCV-225	6,600/2,012	Hydro Products	Santa Fe Construction Co.
RCV-225	6,600/2,012	Hydro Products	Uncommitted
RECON II	1,500/457	Perry Oceanographics	Hunting Surveys Ltd.
RECON III	600/181	Perry Oceanographics	Oceanics Ltd.
RECON V	1,200/366	Perry Oceanographics	Same
RUWS	20,000/6,096	Naval Ocean Systems Center	Same
SCAN	328/100	Underwater Maintenance Co., Ltd.	Same
SCARAB I & II	6,000/1,829	Ametek Straza	AT&T Long Lines
SCORPIO	3,000/914	Ametek Straza	Stolt-Nielsen Rederi A/S
SCORPIO	3,000/914	Ametek Straza	Israel - Government
SCORPIO	3,000/914	Ametek Straza	Same
SEA INSPECTOR	3,280/1,000	Rebikoff Underwater Products	Same
SEA SPY	1,000/105	Admiralty Underwater Weapons Establishment	Underwater and Marine Equipment, Ltd.
SEA SURVEYOR	660/200	Rebikoff Underwater Products	Same
SMARTIE	984/300	Marine Unit Technology, Ltd.	Marine Unit Holdings, Ltd.
SMIT SUB-1000	3,280/1,000	Smit Tak International	Same
SMT 1 & 2	1,200/366	International Submarine Engineering Ltd.	Sonarmarine Ltd.
SNOOPY	1,500/457	Naval Ocean Systems Center	Same
SNOOPY	1,500/457	Naval Ocean Systems Center	Naval Facilities Command
SNURRE	3,280/1,000	Continental Shelf Institute	Same
SPIDER	820/250	Myrens Verkstad A/S	Same
TELESUB	2,000/610	Remote Ocean Systems	Same
TOM 300	984/300	COMEX	Same
TREC 1, 2, 3	1,200/366	International Submarine Engineering Ltd.	Martech International
TREC 4	1,200/366	International Submarine Engineering Ltd.	Horton Maritime Explorations
TREC 5, 6	1,200/366	International Submarine Engineering Ltd.	Ocean Systems Inc.

*No RCV-225 has a cable longer than 1,212 ft (400m), but the vehicle is designed for 6,600 ft operating depth.

TETHERED, FREE-SWIMMING VEHICLES (Continued)

Vehicle	Depth (ft/m)	Manufacturer	Operator
TREC 7, 8	1,200/366	International Submarine Engineering Ltd.	Sub Sea International
TREC 9	1,200/366	International Submarine Engineering Ltd.	Uncommitted
TROV B-1	1,200/366	International Submarine Engineering Ltd.	National Water Resources Institute
TROV O-1	1,200/366	International Submarine Engineering Ltd.	(Not resolved)
TROV E-3	1,200/366	International Submarine Engineering Ltd.	J. Ray McDermott
TROV S-4, 6, 7	3,000/914	International Submarine Engineering Ltd.	Ocean Systems Inc.
TROV S-8	3,000/914	International Submarine Engineering Ltd.	Intersub
UFO 300	984/300	Submersible Television Surveys	Winn Technology
UTAS 478	1,312/400	General Video System	Same

BOTTOM-CRAWLING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
GRANSEOLA	150/46	INCOP, Ancona, Italy	Same
JU 160	197/60	Hitachi Construction	Same
KVAENER MYREN TRENCHING SYSTEM	1,640/500	Kvaerner Brug A/S	Same
PBM	420/128	Sub Sea Oil Services	Same
RUM	6,158/1,877	Marine Physical Laboratory	Same
SEABUG 1	1,000/306	UDI Ltd	Same
SEACAT	656/200	Vickers Oceanics Ltd.	Same
SL 3	164/50	Land and Marine Engineering	Same
SUBTRACTOR	150/46	Maui Divers of Hawaii Ltd.	Same
TALPA	150/46	INCOP, Ancona, Italy	Same
TALPETTA	150/46	INCOP, Ancona, Italy	Same
TM-102	660/201	Techomare S.p.A.	Same
TM III, IV	246/75	Land and Marine Engineering	Same
TRAMP	(Not available)	Winn Technology Ltd.	Same
UNDERWATER BULLDOZER	23/7	Komatsu Ltd	Same
UNDERWATER TRENCHER	70/21	Sumitomo Heavy Industries	Same

TOWED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS	7,874/2,300	Woods Hole Oceanographics Institute	Same
BATFISH	650/198	Bedford Institute of Oceanography	Same
CRAB	13,123/4,000	Institute of Oceanology	Same
DEEP TOW	20,000/6,096	Marine Physics Laboratory	Same
DIGITOW	19,685/6,000	Jet Propulsion Laboratory	Same
DSS-125	20,000/6,096	Hydro Products	One Japanese and One German Industrial firm
GUSTAV	19,685/6,000	Dornier System GmbH	Same
MANKA 01	21,325/6,500	GPK Karlsruhe	Same
NRL System	20,000/6,096	Naval Research Laboratory	Same
RAIE I	19,685/6,000	CNEXO	Same
RAIE II	19,685/6,000	CNEXO	Same
RUFAS I	600/183	NMFS	Same
RUFAS II	2,400/731	NMFS	Same
S^3	6,000/1,829	University of Georgia	Same
SEP	19,685/6,000	Dornier System GmbH	Same
TELEPROBE	20,000/6,096	Naval Oceanographic Office	Same

UNTETHERED REMOTELY OPERATED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
EPAULARD	19,685/6,000	CNEXO	Same
OSR V & H	820/250	Mitsui Ocean Development and Engineering Co.	Same
ROVER	984/300	Heriot-Watt University	Same
SPURV I	12,000/3,650	Applied Physics Laboratory	Same
SPURV II	5,000/1,524	Applied Physics Laboratory	Same
UARS	1,500/457	Applied Physics Laboratory	Same
UFSS	1,500/457	Naval Research Laboratory	Same
Unnamed	2,000/610	Naval Ocean Systems Center	Same
Unnamed	3,000/914	University of New Hampshire	Same

TABLE SALIENT CHARACTERISTICS OF PRESENT AND FUTURE ROVs

Vehicle	Dimensions (cm) L	W	H	Dry Weight (kg)	Speed[1] (KTS)	Power Req.	Dynamic Maneuverability[2] T	H	Y	P	S	R	Launcher/ Clump	Structure[3]	Crew	Horizontal Thruster hp
ANGUS 002	225	127	135	700	1.0	50Hz 415/240V	+[4]	+	+	+	0[5]	+	0	OAF	2	7
ANGUS 003	240	145	145	1,000	2.0	50/60Hz 210/440V	+	+	+	+	+	+	0	OAF	NA	12
BOCTOPUS	320	213	167	970	2.0	33KVA	+	+	+	0	+	+	0	OAF	5	20
CETUS	244	152	122	1,089	3.5	50-60Hz 415/480V	+	+	+	0	+	0	0	OAF	4	8.6
CONSUB 1	271	182	145	1,360	2.0	50Hz 240/415V	+	+	+	0	0	0	0	OAF	4	10
CONSUB 201 & 02	368	213	175	2,900	2.0	50/60Hz 380/415/440V	+	+	+	0	0	0	0	OAF	3	25
CORD II	73	104	140	327	1.5	60Hz 480V	+	+	+	0	0	0	+	OAF	3	3
CURV II	457	183	183	1,565	4.0(S)	120/50Hz 440V	+	+	+	0	0	0	0	OAF	7	20
CURV III	457	183	183	1,814	4.0(S)	50Hz 120/440V	+	+	+	0	0	0	0	OAF	7	20
DART	94	46	31	32	NA	NA	+	+	+	0	+	0	0	OAF	NA	NA
DEEP DRONE	213	137	122	726	1.5	115/440V	+	+	+	0	0	0	0	OAF	5	6
ERIC 10	400	200	200	3,100	2.0	60Hz 440V	+	+	+	0	0	0	0	OAF	5	1
ERIC 11	500	300	180	5,000	NA	400Hz 115V	+	+	+	+	+	+	+	EFF	5	NA
EV-1	132	81	61	107	1.5	60Hz 220/440V	+	+	+	0	0	0	0	OAF	3	NA
FILIPPO	65	65	65	86	0.5	Battery	+	+	+	0	+	0	0	EFF	1	1
IZE																
MANTA 1.5	198	158	107	998	3.0(S)	50Hz 380V	+	+	+	0	0	0	0	OAF	3	3
MURS-100	255	189	150	900	2.5	60Hz 440V	+	+	+	0	0	+	0	EFF	4	4
MURS-300	266	190	163	2,400	1.0(S)	60Hz 220V	+	+	+	0	0	0	0	OAF	2-3	15
OBSERVER DL1	175	NA	150	NA	NA	NA	+	0	+	0	0	0	0	OAF	NA	NA
ORCA I	350	200	200	2,721	NA	50/60Hz 380/440V	+	+	+	+	+	+	0	OAF	4	16
PAP-104	270	120	130	700	4.0	Battery	+	0	+	0	0	0	0	EFF	2	NA
PHOCAS II	200	80	80	227	1.5	50Hz 220V	+	0	+	0	0	0	0	OAF	NA	1
PINGUIN B6	315	175	175	1,626	2.0	NA	+	0	+	0	0	0	0	EFF	NA	NA
RCV-225	51	66	51	82	1.0	50/60 Hz 320/440V	+	+	+	0	+	+	+	EFF	3	0.2
RCV-150	135	122	112	204	2.0	50/60Hz 220/440V	+	+	+	0	+	0	+	OAF	3	15
RECON II	107	96	81	281	1.5	60Hz 220/440V	+	+	+	0	0	0	+	OAF	5	2
RECON III	142	71	61	150	3.0(S)	60Hz 220/440V	+	+	+	0	0	0	0	OAF	3	2.6
RECON V	175	99	81	259	2.5(S)	60Hz 220/480V	+	+	+	0	+	+	0	OAF	3	5
RUWS	335	145	152	3,200	1.5	60Kw	+	+	+	0	0	0	+	OAF	NA	15
SCAN	61	61	36	NA	1.0	50Hz 420V	+	0	+	0	0	0	0	EFF	1	NA

TABLE (CONTINUED)

Vehicle	Dimensions (cm) L	W	H	Dry Weight (kg)	Speed[1] (KTS)	Power Req.	Dynamic Maneuverability[2] T	H	Y	P	S	R	Launcher/ Clump	Structure[3]	Crew	Horizontal Thruster hp
SCARAB I & II	335	183	152	2,268	0.5	448V	+	+	+	0	+	+	0	OAF	3	20
SCORPIO	223	122	163	680	1.0	60Hz 440V	+	+	+	0	+	0	0	OAF	4	10
SEA SPY	127	66	58	102	0.5	240V	+	+	+	0	+	0	0	OAF	3	0.4
SEA INSPECTOR	334	120	61	145	5.0(S)	60Hz 230V	+	+	+	+	0	0	0	EMF	2	2
SMT 1	213	127	127	998	1.5	60Hz 440V	+	+	+	0	+	0	0	OAF	7	14
SMT 2	274	127	127	1,497	1.5	60Hz 440V	+	+	+	0	+	0	0	OAF	7	14
SMIT SUB	220	220	160	700	2.0	NA	+	+	+	0	+	0	0	OAF	NA	NA
SNOOPY	101	66	46	68	1.0	60Hz 115V	+	+	+	0	0	0	0	OAF	2	2
SNURRE	200	180	150	1,200	1.5(S)	420V	+	+	+	0	+	0	0	OAF	4-5	2
TELESUB	140	79	69	104	1.5	60Hz 200/440V	+	+	+	0	+	0	0	OAF	NA	2
TOM 300	360	170	182	2,900	1.5	220/380V	+	+	+	0	+	0	0	OAF	5	12
TREC	119	91	135	181	1.5	60Hz 120V	+	+	+	0	+	0	0	OAF	4	3
TROV B1	159	91	122	544	2.0	60Hz 460V	+	+	+	0	+	0	0	OAF	4	10
UFO 300	91	NA	NA	91	NA	NA	+	+	+	+	+	+	+	EFF	2	NA
TROV-01	213	127	127	726	NA	60Hz 440V	+	+	+	0	+	0	0	OAF	2	NA
SMARTIE	110	110	46	82	NA	50Hz 440V	+	+	+	0	+	0	+	EFF	3	NA
TROV 4	274	127	127	1,179	1.0	60Hz 440V	+	+	+	0	+	0	0	OAF	4	14
UTAS 478	140	55	30	80	2.3		+	+	+	0	0	0	0	EMF	NA	1

[1]Speed at maximum operating depth under zero current conditions. (S) indicates surface speed.
[2]T: thrust; H: heave; Y: yaw; P: pitch; S: sway; R: roll.
[3]OAF: open aluminum framework; EFF: enclosed fiberglass fairing; EMF: enclosed metallic framework.
[4]+: capability.
[5]0: not a capability.
NA: information not available.

TABLE TETHERED, FREE-SWIMMING VEHICLES, DEPTH AND DISTRIBUTION

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
SCAN	1	328/100 (approx)	Operational	Underwater Maintenance Co., Ltd.	Same
PAP-104	128	328/100	Operational	Various NATO Navies	Societie Eca
MURS-100	1	328/100	Operational	Mitsui Ocean Development and Engineering Co.	Same
PINGUIN A1	1	330/101	Operational	VFW Fokker	Same
OBSERVOR DL1	1	600/183	Operational	C.G. Doris	Same
RECON III	5	600/183*	Operational	Oceanics Ltd. (2)	Perry Oceanographics (3)
SEA INSPECTOR	2	656/200	Operational	Rebikoff Underwater Products	Same
SEA SURVEYOR	1	660/200	Operational	Rebikoff Underwater Products	Same
SPIDER	1	820/250	Operational	Myren Verksted A/S	Same
FILIPPO	1	984/300	Operational	Gay Underwater Products	Same
FILIPPO	1	984/300	Operational	Nereides, Orsay, France	Gay Underwater Products
FILIPPO	2	984/300	Construction	Uncommitted	Gay Underwater Products
OBSERVOR III	1	984/300	Construction	C.G. Doris	Same
MURS-300	1	984/300	Construction	Mitsui Ocean Development and Engineering Co.	Same
UFO-300	1	984/300	Operational	Winn Technology	Submersible Television Surveys
SMARTIE	3	984/300	Operational	Marine Unit Holdings, Ltd.	Marine Unit Technology, Ltd.
TOM 300	1	984/300	Operational	COMEX	Same
ANGUS 002	1	1,000/305	Operational	Heriot Watt University	Same
ANGUS 003	1	1,000/305	Construction	Heriot Watt University	Same
CUTLET	3	1,000/305	Operational	Admiralty Underwater Weapons Establishment	Same
SEA SPY	1	1,000/305	Operational	Underwater and Marine Equipment Ltd.	Admiralty Underwater Weapons Establishment
PHOCAS II	1	1,000/305	Operational	Geloginen Tutkimuslaitos	Same
RECON V	1	1,200/366	Construction	Perry Oceanographics	Same
SMT 1 & 2	2	1,200/366	Operational	Sonarmarine Ltd.	International Submarine Engineering Ltd.
TREC 1, 2, 3	3	1,200/366	Operational	Martech International	International Submarine Engineering Ltd.
TREC 4	1	1,200/366	Operational	Horton Maritime Explorations	International Submarine Engineering Ltd.

*RECON III's depth has been upgraded to 1,200 ft (366m)

TABLE (CONTINUED)

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
TREC 5, 6	2	1,200/366	Operational	Ocean Systems Inc.	International Submarine Engineering Ltd.
TREC 7	1	1,200/366	Operational	Sub Sea International	International Submarine Engineering Ltd.
TREC 8	1	1,200/366	Operational	Sue Sea International	International Submarine Engineering Ltd.
TREC 9	1	1,200/366	Construction	Uncommitted	International Submarine Engineering Ltd.
TROV B-1	1	1,200/366	Operational	National Water Resources Institute	International Submarine Engineering Ltd.
TROV 0-1	1	1,200/366	Inactive	(Not resolved)	International Submarine Engineering Ltd.
TROV S-3	1	1,200/366	Operational	J. Ray McDermott	International Submarine Engineering Ltd.
UTAS 478	1	1,312/400	Operational	General Video System	Same
CETUS	3	1,500/457	Operational	ULS Marine Ltd.	Same
CORD II	1	1,500/457	Operational	Harbor Branch Foundation	Same
EV-1	2	1,500/457	Test and Evaluation	Kraft Tank Co.	Same
RECON II	1	1,500/457	Operational	Hunting Surveys Ltd.	Perry Oceanographics
SNOOPY	1	1,500/457	Operational	Naval Ocean Systems Center	Same
SNOOPY	1	1,500/457	Operational	Naval Facilities Command	Naval Ocean Systems Center
ERIC 10	1	1,640/500	Operational	French Navy	C.E.R.T.S.M.
IZE	1	1,640/500	Operational	Sub Sea Surveys Ltd.	Same
SNURRE	1	1,969/600	Operational	Continental Shelf Institute	Same
CONSUB 1	1	2,000/610	Operational	Institute of Geological Sciences	British Aircraft Corp.
CONSUB 201	1	2,000/610	Operational	Sub Sea Surveys Ltd.	British Aircraft Corp.
CONSUB 202	1	2,000/610	Construction	British Aircraft Corp.	Same
MANTIS	2	2,000/610	Operational	Star Offshore Ltd.	OSEL Group
DEEP DRONE	1	2,000/610	Operational	Ametek Straza	Supervisor of Salvage (USN)
TELESUB	1	2,000/610	Operational	Remote Ocean Systems	Same
BOCTOPUS	1	2,170/661	Operational	British Oxygen Co.	Same

TABLE (CONTINUED)

Vehicle	No. Units	Depth (ft/m)	Status	Operator	Manufacturer
CURV II	1	2,500/762	Operational	Naval Ocean Systems Center	Same
CURV II	1	2,500/762	Operational	Naval Torpedo Station	Naval Ocean Systems Center
SCORPIO	1	3,000/914	Operational	Stolt-Nielsen Rederi A/S	Ametek Straza
SCORPIO	1	3,000/914	Operational	Israel - Government	Ametek Straza
SCORPIO	2	3,000/914	Operational	*Ametek Straza	Same
TROV S-4, 6	2	3,000/914	Operational	Ocean Systems Inc.	International Submarine Engineering Ltd.
TROV S-7	1	3,000/914	Construction	Ocean Systems Inc.	International Submarine Engineering Ltd.
TROV S-8	1	3,000/914	Construction	Intersub	International Submarine Engineering Ltd.
TOM-300	1	3,280/1,000	Operational	COMEX Services	COMEX Industries
SEA INSPECTOR	2	3,280/1,000	Construction	Rebikoff Underwater Products	Same
SMIT SUB	1	3,230/1,000	Construction	Smit Tak International	Same
SNURRE	1	3,280/1,000	Operational	Continental Shelf Institute	Same
MANTA 1.5	1	4,291/1,500	Operational	Institute of Oceanology USSR	Same
ORCA	1	6,000/1,829	Operational	Oceaneering International	Saab-Scania
RCV-150	1	6,000/1,829	Operational	Uncommitted	Hydro Products
RCV-150	3	6,000/1,829	Construction	Uncommitted	Hydro Products
SCARAB I & II	2	6,000/1,829	Operational	AT&T Long Lines	Ametek Straza
**RCV-225	2	6,600/2,012	Operational	Seaway Diving	Hydro Products
RCV-225	3	6,600/2,012	Operational	Martech International	Hydro Products
RCV-225	2	6,600/2,012	Operational	SESAM	Hydro Products
RCV-225	1	6,600/2,012	Operational	Esso Australia Ltd.	Hydro Products
RCV-225	6	6,600/2,012	Operational	Taylor Diving and Salvage	Hydro Products
RCV-225	1	6,600/2,012	Operational	Wharton Williams	Hydro Products
RCV-225	1	6,600/2,012	Operational	Oceaneering International	Hydro Products
RCV-225	2	6,600/2,012	Operational	Japanese Navy	Hydro Products
RCV-225	2	6,600/2,012	Operational	Santa Fe Construction Co.	Hydro Products
RCV-225	1	6,600/2,012	Operational	Global Divers & Construction Inc.	Hydro Products
RCV-225	5	6,600/2,012	Construction	Uncommitted	Hydro Products
CURV III	1	10,000/3,048	Operational	Naval Ocean Systems Center	Same
ERIC II	1	19,685/6,000	Construction	French Navy	C.E.R.T.S.M.
RUWS	1	20,000/6,096	Test and Evaluation	Naval Ocean Systems Center	Same

*Lockheed Petroleum Services Ltd., New Westminster, B.C. took delivery of a SCORPIO on 31 July 1979

**No RCV-225 has a cable longer than 1,312 ft (400m), but the vehicle is designed for 6,600 ft operating depth.

TABLE

ROV INSTRUMENTATION

	TV	ST CAM	STE CAM	CINE CAM	MAN-IP	ECHO SOUN	DIR HYD	SCAN SON	S S S	SUB-BOT PROF	C-P MON	UT	RAD	CL	CUR-RENT	TEMP	MAG COMP	GYRO	DEPTH	MAG
ANGUS 002	+(2)	+		+		+	+										+		+	
ANGUS 003	+(2)	+		+			+									+	+		+	
BOCTOPUS	+(2)					+											+		+	
CETUS	+(2)	+		+	+	+				+							+	+(D)	+	+
CONSUB 1	+(2)		+														+		+	
CONSUB 201	+(3)	+	+		+	+			+	+	+						+		+	+
CORD II	+				+	+		+							+	+	+		+	
CURV II	+(2)	+			+	+		+									+		+	
CURV III	+	+			+	+		+									+		+	
DARTS	+																			
DEEP DRONE	+(2)	+				+		+									+		+	
ERIC 10	+	+			+	+		+									+		+	+
ERIC 11	+			+	+(2)	+		+										+	+	
EV-1	+																+		+	
FILIPPO	+																+		+	
MANTA 1.5	+								+											
MURS-100	+				+										+		+		+	
MURS-300	+(2)	+			+(2)	+		+										+	+	
OBSERVOR DL-1	+																		+	
ORCA	+(2)	+	+		+(3)	+	+(2)											+(D)	+	
PAP-104	+																	+		
PHOCUS II	+	+			+	+											+		+	
PINGUIN B6	+					+		+							+				+	
RCV-150	+																	+(D)	+	
RCV-225	+																	+(D)	+	
RECON II	+				+										+		+		+	
RECON III	+																+		+	
RECON V	+				+												+		+	
RUNS	+(2)	+			+(2)	+	+(2)	+									+		+	
SCAN	+	+																		
SCARAB I & II	+(2)	+			+(2)	+		+										+(D)	+	+
SCORPIO	+				+	+		+										+(D)	+	
SEA INSPECTOR	+																	+(D)	+	
SEA SPY	+																+		+	
SHARTIE	+(3)																+	+(D)	+	
SMT 2	+(3)	+	+		+(2)	+	+				+	+	+	+				+	+	
SMIT SUB	+																			
SNOOPY	+			+													+		+	
SNURRE	+(2)	+	+	+(2)	+	+	+(2)											+	+	
TELESUB	+																+		+	
TOM 300	+(2)	+			+	+											+	+	+	
TREC	+					+											+		+	
TROV	+				+	+	+										+		+	
UFO 300	+	+									+						+		+	
UTAS 478	+					+										+	+		+	

Legend

TV: closed circuit television
ST CAM: still camera
STE CAM: stereo-cameras
CINE CAM: cine camera
MANIP: manipulator
ECHO SOUN: echo sounder
DIR HYD: directional hydrophone

SCAN SON: scanning sonar
SSS: side scan sonar
SUB-BOT PROF: sub-bottom profiler
C-P MON: corrosion potential probes
UT: ultrasonic measurement probes
RAD: radiographic analysis device

CL: cleaning device
CURRENT: current meter
MAG COMP: magnetic compass
GYRO: gyrocompass, +(D) = directional gyro
DEPTH: depth measurement/indicator
MAG: magnetic sensing device (pipeline or cable tracking)

APPENDIX D

TABLE D.1 - STEEL-PILED PLATFORMS - UK AND NORWEGIAN SECTORS (NORTH OF 56°N)

FIELD	Platform designation	Approximate date of installation	Water depth (m)	PLATFORM DESCRIPTION				
				Number of piled legs	Number of node levels	Number of nodes under water	Total indicative length of external members (m)	Dimensions at seabed (m x m)
Auk	A	1974	85	8	5	68	2700	36 x 64
Beryl	Flare I	1976	117					
	Flare II	1976						
Brent	A	1976	138	6	5	85	4800	75 x 77
Claymore	A	1976	117	4	6	84	3600	62 x 55
Forties	FA	1974	107	4	6	60	3000	71 x 85
	FB	1975	123	4	6	60	3800	75 x 90
	FC	1974	128	4	6	60	4000	75 x 90
	FD	1975	123	4	6	60	3800	75 x 90
Frigg	QP	1975	105	4	5	60		27 x 37
	DP2	1977	105	4	5	50		44 x 62
Heather	A	1977	144	8	7	98	5000	
Montrose	A	1976	92	8	5	68	2700	
Murchison		1979	157	4	6	72		75 x 74
Ninian	Southern	1978	138	4	5	45	4800	
	Northern	1978	138					
Piper	A	1975	146	4	7	98	5200	62 x 62

(cont'd)

Table D.1 (cont'd)

FIELD	Platform designation	Approximate date of installation	Water depth (m)	PLATFORM DESCRIPTION				
				Number of piled legs	Number of node levels	Number of nodes under water	Total indicative length of external members (m)	Dimensions at seabed (m x m)
Tartan		1979		4	7	84		66 x 63
Thistle	A	1976	168	4	6	56	6800	76 x 73
Albuskjell	2/4F	1977	71	12	4	48	2500	40 x 60
	1/6A	1977	71	12	4	48	2500	40 x 60
Cod	A	1975	71	8	4	48	1500	30 x 40
Edda	C	1976	71	12	4	48	2500	40 x 60
Ekofisk	A	1973	71	8	4	48	1500	30 x 40
	B	1973	71	12	4	48	2500	40 x 60
	C	1972	71	12	4	48	2500	40 x 60
	D (West)	1974	71	8	4	48	1500	30 x 40
	FTP	1972	71	12	4	48	2500	40 x 60
	P	1974	71	4	4	32		
	Q	1973	71	4	4	32		
	R	1975	71	8	4	48	1500	30 x 40
	H	1978	71	4	4	32		
Eldfisk	A	1975	71	12	4	48	2500	40 x 60
	B	1976	71	12	4	48	2500	40 x 60
	FTP	1976	71	12	4	48	2500	40 x 60
Tor	E (1)	1976	71	8	4	48	1500	30 x 40
Hod/Valhall	(1)	1979	70					
	(2)	1979	70					

Source: CIRIA UR-13, p 92-93.

Note: All information is indicative only.

APPENDIX D

TABLE D.2 - NORTH SEA: CONCRETE GRAVITY PLATFORMS - ALL SECTORS

FIELD	Platform designation	Approx. date of installation	Water depth (m)	Design type
Beryl	A	1975	117	Condeep
Brent	B	1976	138	Condeep
	D	1978	138	Condeep
	C	1978	138	Sea tank
Cormorant	A	1978	140	Sea tank
Dunlin	A	1977	153	ANDOC
Ekofisk	Ekofisk Centre	1973	71	Doris
Frigg	CDPI	1975	104	Doris
	MCP 01	1976	104	Doris
	TP 1	1976	104	Sea tank
	TCP 2	1977	104	Condeep
Ninian	Central	1978	138	Doris
Statfjord	A	1977	146	Condeep

Source: CIRIA UR-13, p 94.

Note: All information is indicative only.

APPENDIX E

UNDERWATER INSPECTION: US, UK, AND NORWEGIAN STATUTORY REQUIREMENTS (1978)

Source: R.Frank Busby, Underwater Inspection/Testing/Monitoring of Offshore Structures, (Washington DC, February 1978) - Excerpts.

2.1.2.a Department of the Interior (Geological Survey)

Under the Outer Continental Shelf Lands Act, referred to earlier, the USGS is responsible for overseeing and regulating the structural integrity and operational safety of offshore drilling and production equipment. It requires (under OCS Order Number 8, Gulf of Mexico and Western Region Pacific area, third-party inspection by the Operator to certify that the structure will be constructed, operated and maintained as described in the application (1).

The USGS is presently focusing its efforts to the question of third party verification. In this area the Marine Board of the National Research Council was requested to undertake a review of the verification practices and the need for such practices concerning structural adequacy of fixed offshore oil and gas platforms. The results of the National Research Council's study are contained in reference (2); in short, the study recommends initiation of a third party verification system. An industrial critique of the Marine Board's recommendations is contained in references (3) and (4). Directly related to this study is a Marine Board recommendation that the USGS should establish procedures for the routine reporting of platform structural conditions and analysis. Within the verification system the Marine Board further recommends underwater inspection at four distinct stages:

a) immediately after installation to assure that the platform has been installed according to plan and that no critical damage has occurred. (If damage has occurred, then inspection should assure that the repair is adequate.)

b) inspection (reverification) when changes in configuration are made which affect structural integrity.

c) inspection (reverification when reports are necessary because of major platform damage due to ship collisions, corrosion and/or storms.

d) planned, periodic inspection.

The Geological Survey stated (5) that periodic reverification of platforms will be required to assure structural integrity throughout their operational life. Reverification will be required following major storms where damage is suspected or as a result of other events that could impact the structure. Reverification will be carried out in accordance with an approved plan submitted by the operator.

3.1.1 United Kingdom

In accordance with the terms of the Continental Shelf Convention, Parliament enacted the Mineral Workings (Offshore Installations) Act of 1971, to provide for the safety, health, and welfare of persons on installations concerned with the underwater exploitation and exploration of mineral resources in the waters in or surrounding the United Kingdom. The Petroleum and Submarine Pipelines Act of 1975 extended the scope of the earlier Act to cover any other installation, whether floating or not, which may be manned and which is used in connection with conveyance of things by means of a pipe constructed in or under the sea.

Under the powers granted in the Mineral Workings Act, the Secretary of State made the Offshore Installations (Construction and Survey) Regulations in 1976. These regulations require all offshore installations established or maintained in waters around the U.K. to be certified as fit for the purposes specified, and provide statutory force to ensuring that all aspects of the design and construction process are subject to an independent professional critique.

In regard to fixed platforms (conductor pipes, drilling risers and riser pipes carrying oil or gas are not considered a part of the installation): none may be established or maintained in relevant U.K. waters unless a valid Certificate of Fitness is in force for that platform. The Secretary of State may himself issue Certificates of Fitness, but, in practice, the following organizations have been authorized to do so and one or the other have carried out the Certification program:

American Bureau of Shipping
Bureau Veritas
Det Norske Veritas
Germanischer Lloyd
Halcrow Ewbank and Associates Certification Group
Lloyds Register of Shipping

An application for a Certificate of Fitness shall be made by the owner of the installation. The Certificate of Fitness is valid for such a period as the Certifying Authority may specify, not exceeding five years from the date of completion of the last major survey carried out pursuant to Regulations.

A "major survey" for newly constructed platforms is conducted on the surface and it is a continuous activity covering the whole of the construction period and the installation and testing of equipment. For fixed platforms it is the last above-water opportunity to inspect and test those elements that will be permanently submerged.

After an installation has been subjected to a major survey, a Certifying Authority may accept - instead of a subsequent major survey - a series of continuous surveys conducted in rotation in conjunction with annual surveys if satisfied that the results so obtained are equivalent to those which would have been obtained in the course of a major survey. The following deals with annual surveys:

(2)(a) "In respect of every installation in relation to which a certificate of Fitness is in force, there shall be carried out on behalf of the Certifying Authority which issued that certificate surveys (herein referred to as "annual surveys") of a selection of the members, joints and areas of the primary structure of the installation, the parts of the installation...and its equipment, the selection being sufficient in number, disposition or extent (as the case may be) to provide reasonable evidence as to whether the installation and its equipment continue to comply with the requirements of Schedule 2, or such of the same as may be applicable.

(b) The first annual survey shall be carried out within not less than 9 nor more than 18 months after the date of issue of the Certificate of Fitness and thereafter similar surveys shall be carried out within not less than 9 nor more than 15 months of each anniversary date of issue of the certificate during the period in which it is in force."

Offshore Installations (Construction and Survey) Regulations 1978

The annual surveys are not the only requirements for underwater inspection. At any time while an application for a Certificate of Fitness is being considered or is in force an additional survey may be required if:

a) the structure is damaged, or suspected of being damaged in a manner likely to impair safety, strength or stability, or

b) it demonstrates signs of deterioration to an extent likely to impair safety, strength or stability, or

c) its equipment is subject to any alteration, repair or replacement.

In the event that any of the three events outlined above take place, the owner should immediately notify the appropriate Certifying Authority of the occurrence of the event in such detail that the Authority can determine whether or not an additional survey should be carried out.

In 1974 the Department of Energy issued "Guidance on the Design and Construction of Offshore Installations" to explain the procedure whereby fixed and mobile offshore installations are certified as being fit for their purpose in accordance with the Offshore Installations (Construction and Survey) Regulations of 1974. On the basis of experience gained and suggestions made during the three year operation of the certification scheme, the Department of Energy has revised and rearranged this publication into a new format which will be published in early 1978 (13), it is not, however, a legal document.

Under the U.K. certification scheme the owner is responsible for arranging for surveys as they become due, and the Certifying Authority surveyor should agree with the particulars of destructive and non-destructive tests; the number and frequency or circumstances in which tests should be made and the competance of the personnel and organizations concerned. He should monitor all tests and request spot checks and confirmatory tests to be made as judged necessary.

The DOE document defines three types of surveys: Major Surveys (applies only to mobile installations that have not previously been certified); Major Surveys: re-certification; and Annual Surveys. The later two categories apply to fixed structures (and mobile as well) and define the scope of the underwater inspection.

U.K. regulations are not fixed and unbending. In the event of a difference arising on the application of the regulations which cannot be resolved between the owner and Certifying Authority, the Certifying Authority should, at the formal request of the owner, refer the matter to the DOE with an agreed precis of the points of difference. Final judgement is made by DOE. As of June 1977 there were 103 fixed platforms in U.K. waters to which these regulations apply (9).

3.1.2 Norway

The Norwegian Petroleum Directorate is the Certifying Authority for structures in Norwegian waters. The legal basis for platform inspection is a Royal Decree of 9 July 1976 relating to safe practice for the production, etc., of submarine petroleum resources. In practice, the Petroleum Directorate employs the classification society Det Norske Veritas to carry out certification work and surveys on its behalf.

A draft of "Provisional Guidelines for the Inspection of Structural Parts on Production and Shipment of Installations and Pipeline Systems" was issued by the Petroleum Directorate on 2 April 1977 (14). In many respects the Norwegian regulations (though still not finalized) follow English regulations. A major difference is that Norwegian regulations consider the riser as a part of the structure; they have also included inspection criteria for submarine pipelines. The English have not yet issued pipeline inspection criteria.

Although the Petroleum Directorate's Guidelines are provisional, they are none-the-less an official opinion of the Norwegian Government and, since National regulations and rules take precedence over classification society rules, it is appropriate to review these regulations regardless of subsequent modifications.

APPENDIX F

Cost Estimate (See Figures 4.3 and 4.4)

Job: Tie-in pipeline to Riser

Method A: Mechanical connection , with 6 saturation divers.
Method B: Hyperbaric weld, with 8 saturation divers.

General Assumptions

MOB/DEMOB for personnel and equipment = $20,000.
Set-up/tear-down of equipment = $10,000.
During which personnel and equipment are "on-hire".
Decompression from storage depth requires one hour/6 feet.
Total number of days required:

2 days set-up
0.5 day transit (including compression)
7.5 days working and delays (at depth)
4 to 8 days decompression (including transit)
1 day tear-down and release equipment.

Total working hours at depth = 4 x 22 = 88.

Equipment and Personnel Rates

Method A: Support vessel MOB/DEMOB = $10,000 (neglected).
Support vessel cost = $30,000/day.
Diving spread equipment = $5,000/day
Diving spread personnel (35 men) = $10,000/day.

Method B: Support vessel MOB/DEMOB = $10,000 (neglected).
Support vessel cost = $50,000/day.
Diving spread equipment = $5,000/day.
Hyperbaric habitat and alignment equipment = $5,000/day.
Diving spread personnel (37 men) = $10,500/day.

For both methods additional costs are:

(1) Gas (during saturation/decompression).
(2) Depth pay (during saturation/decompression).

Gas cost and depth pay are estimated on following basis during saturation.
Depth pay is based on $627/400 feet + $1.21/additional foot.

APPENDIX F (cont'd)

TABLE F.1 DEPTH PAY AND GAS COST VS DEPTH

Depth (ft)	Depth pay ($ per man day at depth)	Gas cost ($/day)
400	627	10,000
500	748	12,000
600	869	12,500
700	990	13,000
800	1,111	13,500
900	1,232	14,000
1,000	1,354	14,500
1,100	1,474	15,000

Gas and depth pay are prorated during decompression at depth and gas costs of depth.

TABLE F.2 ESTIMATED DECOMPRESSION PERIODS

Saturation depth	Total days decompression
400	2.78
500	3.47
600	4.17
700	4.86
800	5.56
900	6.25
1000	6.94
1100	7.64

TABLE F.3 COST OF DECOMPRESSION (GAS AND DEPTH PAY ONLY)

Saturation depth (ft)	6 Men ($)	8 Men ($)
400	24,000	25,400
500	33,830	36,310
600	44,190	47,790
700	54,970	59,830
800	66,380	72,710
900	78,310	86,290
1000	90,770	100,570
1100	103,650	115,411

APPENDIX F (cont'd)

TABLE F.4 RATES IN EFFECT DURING PROJECT

Day	Activities	Method A Rates ($1,000)	Method B Rates ($1,000)
1	Transport equipment & personnel, set-up	MOB/DEMOB (20+) Set-up (10) Equip.+personnel+vess. (5 + 10 + 30)	MOB/DEMOB (20) Set-up (10) Equip. +pers.+vessel (10 +10.5 + 50)
2	cont'd, and start transit	Equip.+personnel+vess. (5 + 10 + 30)	Equip. +pers.+vessel (10 +10.5 + 50)
3 4 5 6 7 8 9 10	Transit and compression Working/delays (on site) Complete job	Costs: Equip., pers., depth, gas, vessel @ "working" day rates (as a function of depth) See table F.5.	Costs: Equip., pers., depth, gas, vessel @ "working" day rates (as a function of depth) See table F.5.
11 12 13 14 15 16 17 18 19	Start decomp. and transit End decomp. (400') End decomp. (500',600') End decomp. (700') End decomp. (800',900') End decomp. (1000') End decomp. (1100') Teardown/release equip. and vessel.	Costs: Equip., pers., depth, gas, vessel @ "decomp." day rates See table F.5	Costs: Equip., (@5.5) pers., depth, gas, vessel @ "decomp." day rates See table F.5

APPENDIX F (cont'd)

TABLE F.5 COSTS

Depths	"Working" rate Cost/day ($1,000)	Total for 8 days "Working"rate ($1,000)	"Decomp." Cost/day ($1,000)[a]	Total "decomp." for required No. of days ($1,000)
METHOD A				
400	58.7	469.6	46.3	185.7
500	61.5	492.0	47.27	236.32
600	62.7	501.6	51.44	257.19
700	63.9	511.6	51.58	309.5
800	65.1	521.2	51.27	358.9
900	66.4	531.2	54.5	381.0
1000	67.6	540.8	54.28	434.2
1100	68.8	550.8	54.2	487.6
METHOD B				
400	85.5	684.0	67.5	270.0
500	88.5	708.0	68.46	342.3
600	89.9	719.6	73.0	364.99
700	91.5	732.0	73.0	438.2
800	92.9	743.2	72.96	510.7
900	94.3	754.8	76.5	535.5
1000	95.8	766.4	76.3	611.0
1100	97.3	778.4	76.33	687.0

Note (a) Some values in error due to decompression estimations rounding off to nearest day.

TABLE F.6 COST SUMMARY (Numbers from Tables F.1 to F.5 are rounded to nearest thousand).

Depth (ft)	METHOD A (Costs $1,000)				METHOD B (Costs $1,000)			
	Day 1 & 2	Working	Decomp.	Total	Day 1 & 2	Working	Decomp.	Total
400	120	470	186	775	171	684	270	1125
500	120	492	236	848	171	708	342	1221
600	120	502	257	879	171	720	365	1256
700	120	512	310	941	171	732	438	1341
800	120	521	360	1001	171	743	511	1425
900	120	531	381	1033	171	755	535	1461
1000	120	541	434	1095	171	766	611	1548
1100	120	551	488	1159	171	778	687	1636