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Lower cost hydrocarbon production: an achievable objective utilising ROV tooling systems

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SYNOPSIS

Despite the dramatic collapse in the price of oil in 1986 the 1980s have seen a continuous development of equipment and procedures aimed at ensuring that technology exists to produce hydrocarbons in deepwater and in hostile environments. A crucial aspect of these developments has been the method of intervention for subsea maintenance which in the majority of areas has concentrated on some form of remotely operated vehicle (ROV).

Esso Exploration and Production (UK) has been particularly active with its Esso Deepwater Integrated Production System (EDIPS) project initiated in 1985. One of the results of that program was the establishment of design principles for a subsea intervention system, based upon simple ROV transportable tool packages, which could be deployed by any of the major work class ROVs. A tool package designed to replace subsea control pods was successfully tested in 150m water depth and proved the tool to be a very efficient means of component replacement.

In concurrent developments, Fuel Subsea Engineering Limited has prepared designs for Integrated Mini Production (IMP) systems, based on a clustered well concept, which offer a very low cost means of subsea manifolding. Combination of the ROV intervention principles, established in the EDIPS program, with the IMP subsea production system concept, has resulted in designs for diverless maintained subsea production systems which are operable in any water depth down to 1000m and may also be cost effective, relative to traditional diver intensive intervention procedures, in comparatively shallow water depths.

INTRODUCTION

The dramatic fall in the market value of oil in 1986, combined with the maturing of the North Sea oil arena, has resulted in strong incentives for the development and deployment of lower cost hydrocarbon production systems.

The life cycle cost of such production systems results from both the initial capital cost and the in-service operating costs. A further factor often significant in economic evaluation of a potential field is cash flow, and therefore minimising pre-investment will generally have a significant, positive, influence on economic evaluation of offshore hydrocarbon production developments.

Since 1984, several subsea production system concept designs have been developed in which means have been considered to achieve the key financial objectives of:

1. minimised pre-investment;
2. low capital cost;
3. minimised operational cost.

Over the same period, major development studies have been undertaken in order to devise methods for diverless maintenance of subsea production systems. It is the convergence of ideas and technology developed for deepwater production systems and current designs for low cost shallow water production systems, that has promoted designs for subsea production systems that are remotely maintainable and also meet the key financial objectives of today's oilfield developments.

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AN APPROACH TO SUBSEA MAINTENANCE

The Esso Deepwater Integrated Production System (EDIPS) programme,[1] was initiated by Esso Exploration and Production (UK) Ltd in 1985 with the objective of ensuring that technology would be available to produce hydrocarbons in 600–1000m water depths, in harsh environments on the UK continental shelf. A hypothetical field development scenario

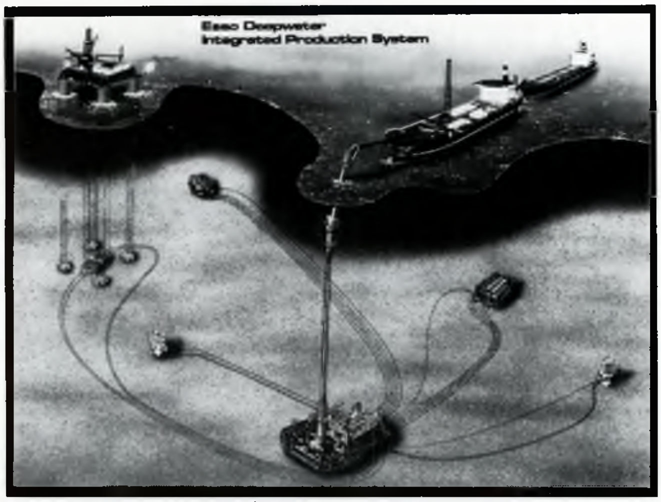

Fig 1: EDIPS field development scenario

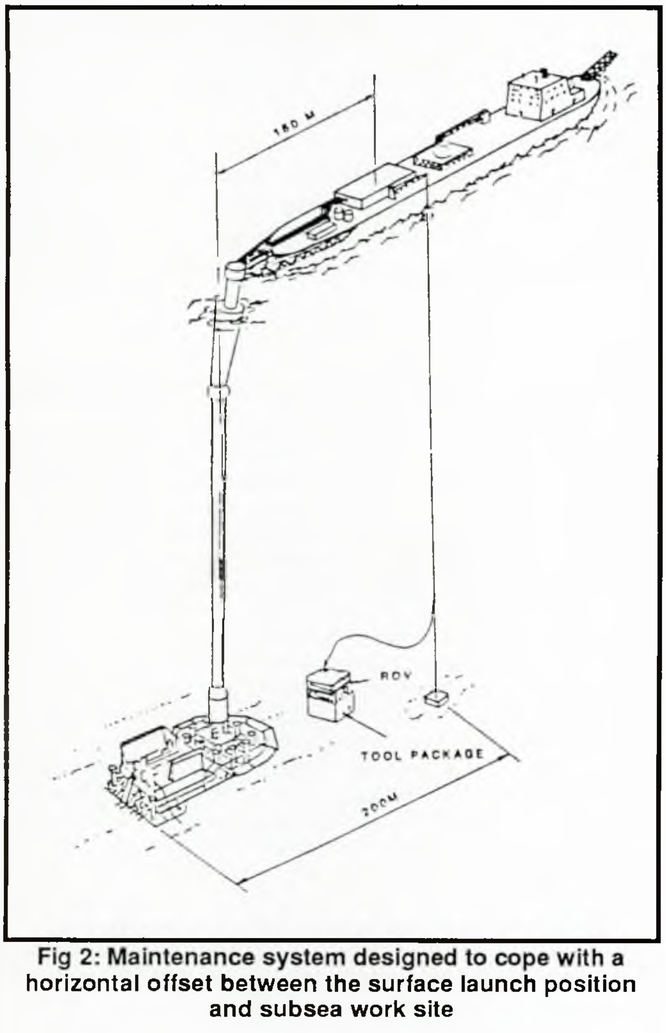

Fig 2: Maintenance system designed to cope with a horizontal offset between the surface launch position and subsea work site

was assumed in order to investigate the various technologies involved; this is illustrated in Fig 1.

The system comprised a tension leg platform (TLP), two underwater manifold centres (UMC), two satellite wells (SSW), a single anchor leg mooring (SALM) with a production manifold at the base (RBM), and a floating production and storage unit (FPSU).

The riser base manifold (RBM) commingles production from the UMC and satellite well for processing and storage

Table I: Analysis of failure modes for period 1970–1978

Failure mode	Numbers	%
Downhole (includes DHSVs)	13	20
Connectors and seals	6	9
Valves and actuators	8	12
Controls and umbilicals	14	21
Flowlines and pipelines	1	1
Catastrophic marine damage	4	6
Unknown	0	0
Total no of failures	46	69
* Total population = 66		

onboard the FPSU, and handles routing of the TLP processed crude, injection water, gas-lift gas, pumpdown tools, and electro-hydraulic controls for all the subsea systems. The manifold incorporates several 3, 6, and 12 in insert valves, diverters, and isolation valves, as well as four electro-hydraulic control pods mounted on a control distribution module (CDM).

A key consideration in the design of the RBM was the manner in which repairs were to be effected, given the proximity of the FPSU.

The presence of the FPSU, a tanker of approximately 250 000t moored to a SALM buoy, provided a potential platform for supporting subsea maintenance operations but because of tanker weathervaning, maintenance operations had to be capable of being safely abandoned at approximately 6h notice, without additional complexity. A further factor to be considered was the shape of the vessel and the mooring arm design, which required that any deck mounted launch equipment associated with the subsea maintenance system be located a considerable distance aft of the bow of the FPSU. As illustrated in Fig 2, this produced a requirement for the maintenance system to cope with a horizontal offset between the surface launch position and subsea work site of 150–200m.

Maintenance of the RBM was considered at three levels as follows:

Level 1: Inspection;
Recovery of components weighing less than 2t.

Level 2: Recovery of modules weighing up to approximately 40t.

Level 3: Recovery of the complete manifold, a module weighing 630t.

Of particular relevance to developing cost effective ROV maintenance techniques was the development of designs to cope with level 1 maintenance. These included:

1. A valve retainer and tool package designed to enable commercially available ROVs to replace subsea valves and chokes.
2. Design of a connector and ROV tooling to enable a commercially available ROV to replace subsea control modules.
3. A range of tools enabling an ROV to operate 3, 6 and 12 in manual subsea valves.
4. Design of a flowline connector enabling an ROV to replace seals and fallible connector elements.

THE REQUIREMENT FOR SUBSEA MAINTENANCE

An important element in developing the EDIPS maintenance philosophy was the perception of how frequently these tasks would need to be undertaken, an aspect which has

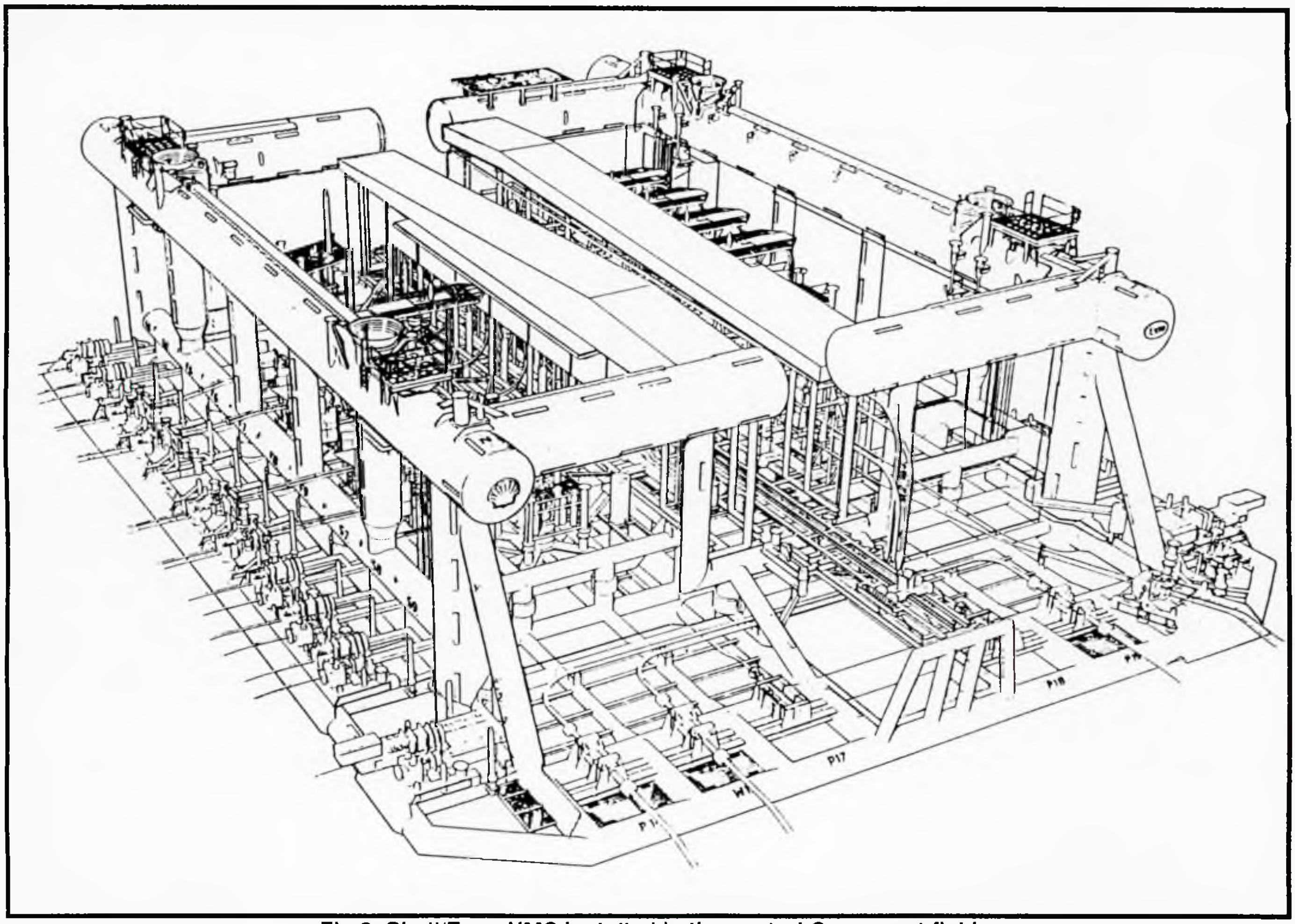

Fig 3: Shell/Esso UMC installed in the central Cormorant field

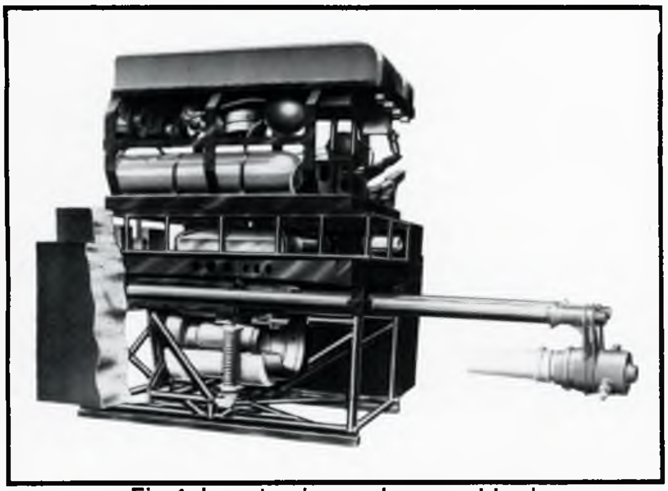

Fig 4: Insert valve replacement tool

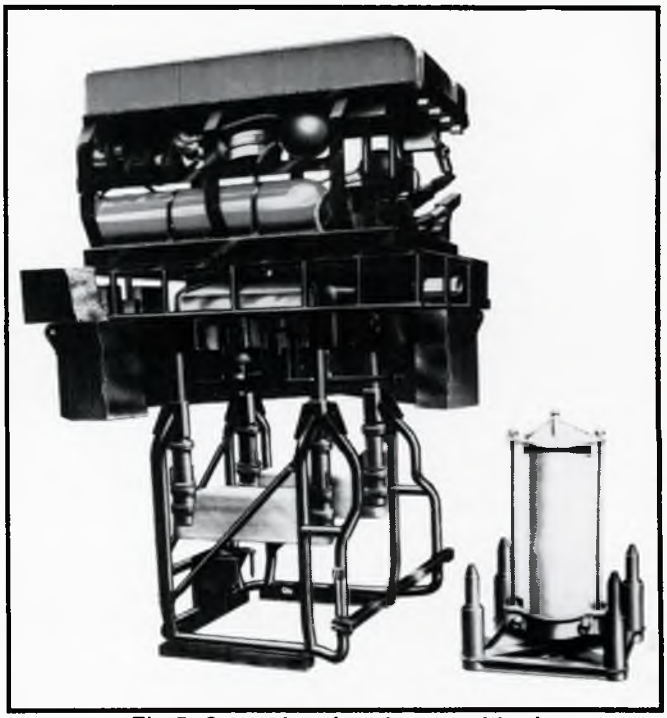

Fig 5: Control pod replacement tool

changed dramatically since the early 1980s when the Shell/ Esso UMC (Fig 3) was installed in the Central Cormorant field.

The UMC incorporated similar components, particularly valves and control pods, to those envisaged for the EDIPS RBM. Maintenance of valves and control pods on the UMC was to be by a remote maintenance vehicle (RMV) which had already been exhaustively and successfully proven on Exxon's submerged production system (SPS) in the Gulf of Mexico. The RMV could change-out several components in a single dive but required trained pilots and technicians to operate and maintain the vehicle and associated systems. The design and operating philosophy of the RMV presumed a need for fre-

Table II: Tool operating sequence

Step	*Description*
1	ROV transports tool package to worksite and docks
2	Tool deploys compensation weight
3	Tool retrieves failed choke or pod
4	ROV undocks, returns to surface with failed component
5	ROV is uncoupled from tool package and makes an inspection and cleaning dive (optional)
6	Pod or choke is fitted into the tool package and tested
7	Final function tests carried out; ROV is mated with the tool package, ROV is launched, driven to worksite and redocked
8	Tool resets valve or choke on to receiver or stump; choke product bore seal is pressure tested
9	Tool picks up weight compensator, restores its weight and trim
10	ROV undocks and returns to surface

quent and extensive component replacement and reflected the level of confidence, and design status, of subsea production systems 10–15 years ago.

In practice the reliability performance of subsea systems has been very good. For example, operational experience with the UMC has shown that in its first four years of operation no subsea fault resulted in total system shut-down, and percentage downtime of individual UMC wells varied from 0–5%.[2] To date only 112h out of a cumulative total of 300 000h of UMC production has been lost due to subsea equipment failure.[3]

Research into the cause and frequency of failure in subsea systems over the period 1960–1984,[4] and thus concurrent with the development of SPS and UMC maintenance philosophy, concluded that subsea equipment could be on-line and ready to produce 99.5% of the time. However, during the 1970s in particular subsea production equipment had a poor reliability record with 28 out of 66 subsea installations suffering failures related to control systems, valves and connectors; this is shown in Table I.

More recent experience with the Texaco Highlander subsea system installed in the North Sea showed that in the first year of operation, when infancy failures should peak, failure of subsea equipment resulted in only 0.7% downtime.[5]

With subsea maintenance proving to be an infrequent event, perhaps only 0.02 failures per well per year relating to non downhole factors, emergency intervention will seldom be necessary. Unfortunately, the infrequent failure may not be long delayed in a specific case and more than one failure may occur with unpredictable timing, therefore, means of rectifying a subsea failure must be rapidly deployed if subsea well availability is to remain better than 99%.

Nevertheless, the probable low frequency of intervention allows an alternative less costly strategy for maintenance to be adopted than that utilised on the UMC system, which was geared to more frequent intervention.

This low frequency use of maintenance equipment in the subsea environment does however set its own challenges. Infrequent use of maintenance equipment requires that it is very easy to operate in the field and within the capability of operators and technicians using the equipment for the first time, without extensive training. This is a very different design scenario to that adopted when frequent intervention is presumed, when it may be practical and cost effective to employ specialist staff to maintain and service the maintenance system.

As the EDIPS maintenance system was expected to be deployed very infrequently and was to be deployed by ROV, it was axiomatic that maintenance tooling would utilise equipment and designs that a competent ROV operator could be expected to service, without recourse to specialist staff. Furthermore, the client oil company had to be free to tender inspection and maintenance contracts as and when it was judged to be commercially prudent. Thus maintenance tooling was designed to be compatible with the majority of work class ROVs so that most, if not all, ROV operators would be free to tender on an equal basis.

The above features, which can be characterised as providing operational simplicity, are now considered much more important than the older design objectives, characterised as providing operational efficiency, as seen in the RMV.

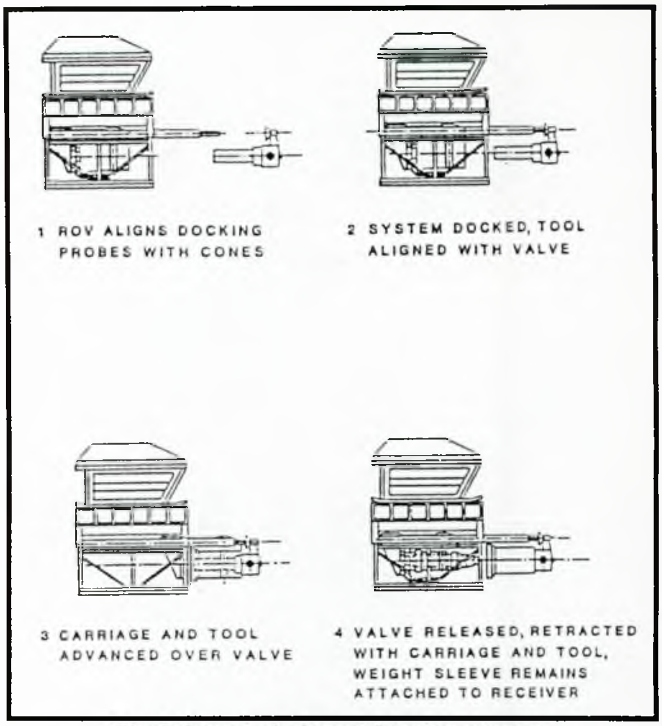

Fig 6: Insert choke retrieval sequence

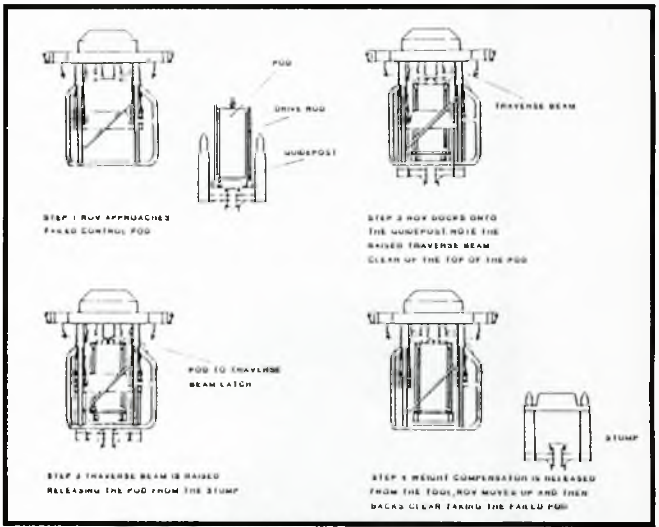

Fig 7: Control pod retrieval sequence

THE EDIPS MAINTENANCE SYSTEM

The EDIPS system, based on ROV transportable tool packages, shown in Figs 4 and 5, demonstrates the emphasis on

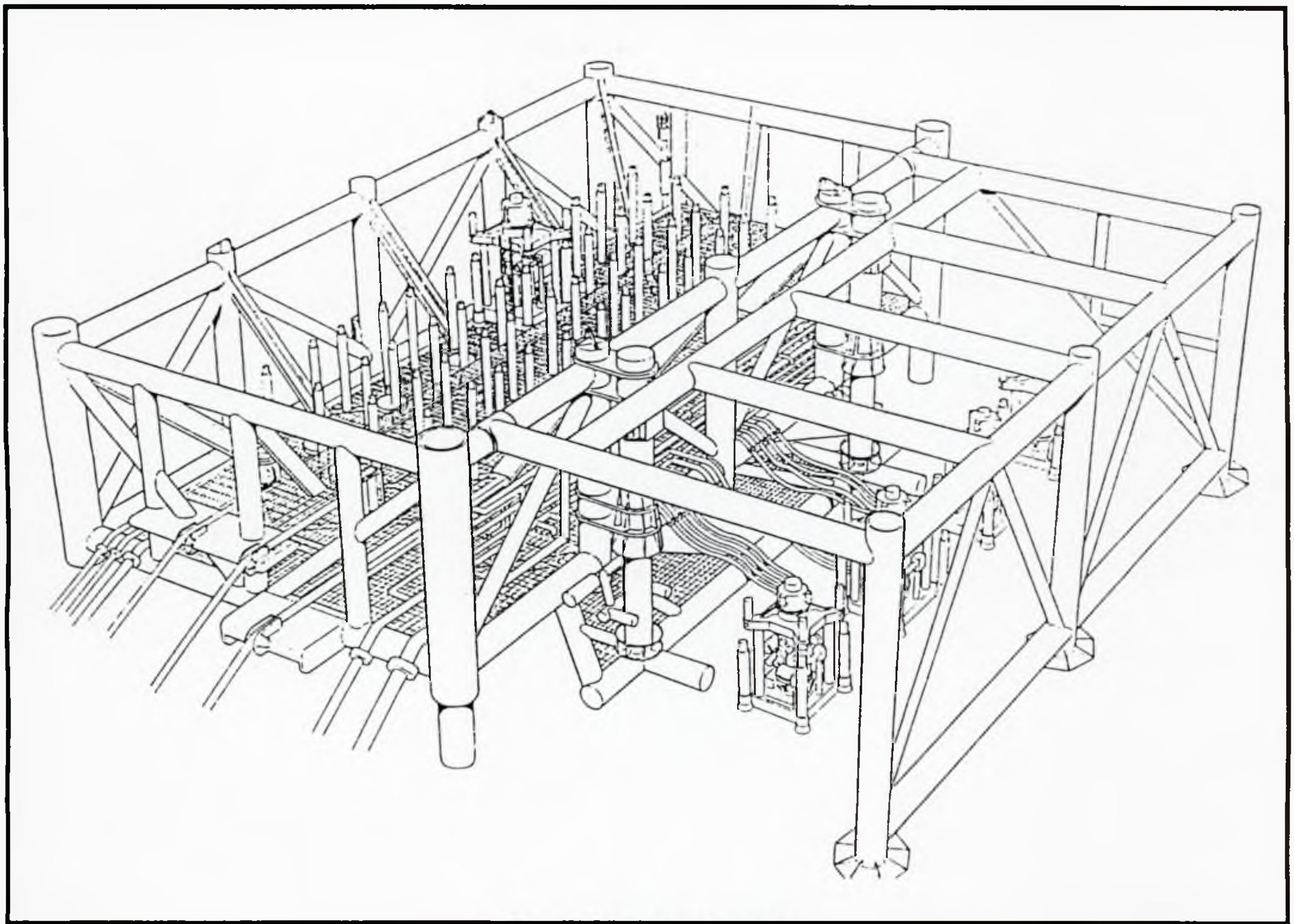

Fig 8: Highlander template

operational simplicity. Each package mates to a common interface skid in which structural, hydraulic and electrical systems are configured to enable the skid to interface with most work-class ROVs. Use of the interface skid, capable of accepting several ROVs, was important to maintain 'contracting' flexibility. It also had several technical advantages, the most important of which was that the interface skid, bolted to the ROV, could contain all electrical and hydraulic control and telemetry equipment, leaving tool packages with only the most basic hydraulic components.

The EDIPS system requires two 'trips' subsea to exchange a single component. This philosophy was selected because it resulted in a fundamentally simpler tool than would be required for a single-trip operation. The two-trip operation also offered simpler operational procedures and, because tool package weight and complexity were minimised, also offered the potential to employ a wider choice of suitable ROVs.

Finally, each tool package was to accommodate equipment of varying size from different manufacturers in order to retain freedom of choice of vendor for subsea equipment.

To date detail designs of two tool packages have been completed; for control pod replacement and for exchanging valves or chokes. The choke tool operates horizontally and the pod tool vertically, but both tools embody similar operational principles and sequences as outlined in Table II.

The component retrieval operation for the choke tool and pod tool is shown in Figs 6 and 7 respectively; replacement of the new component is essentially the reverse of the retrieval sequence.

Tests conducted at the Underwater Test Centre, Fort William, in October 1988, with a prototype control pod replacement tool package operated by a 'rigworker' ROV, demonstrated that the operation could be conducted in current exceeding 0.75 knots and in poor visibility. Eight control pod replacement operations were completed in six working days in water depths down to 150m with a variety of ROV piloting procedures and with several pilots, all of whom accomplished the pod change-out operation at the first attempt.

The control pod change-out operation proved to be very efficient as retrieval and replacement each required only 30 min of ROV time on site, with approximately 2h deck time between dives. This deck time allowed for fitting the replacement pod to the tool package and carrying out function tests on pod, tool and ROV, prior to redeployment. In 150m of water depth, which is typical of northern North Sea water depths, transit time, including launch or recovery, should not exceed 1h. A complete control pod replacement could, therefore, be achieved within 8h of the ROV arriving on location.

AN APPROACH TO SUBSEA PRODUCTION SYSTEM DESIGN

Most subsea production systems located in diver accessible water depths can be maintained by replacement of failed components, because a diver can be utilised to undertake most tasks that an onshore technician might undertake. The Texaco

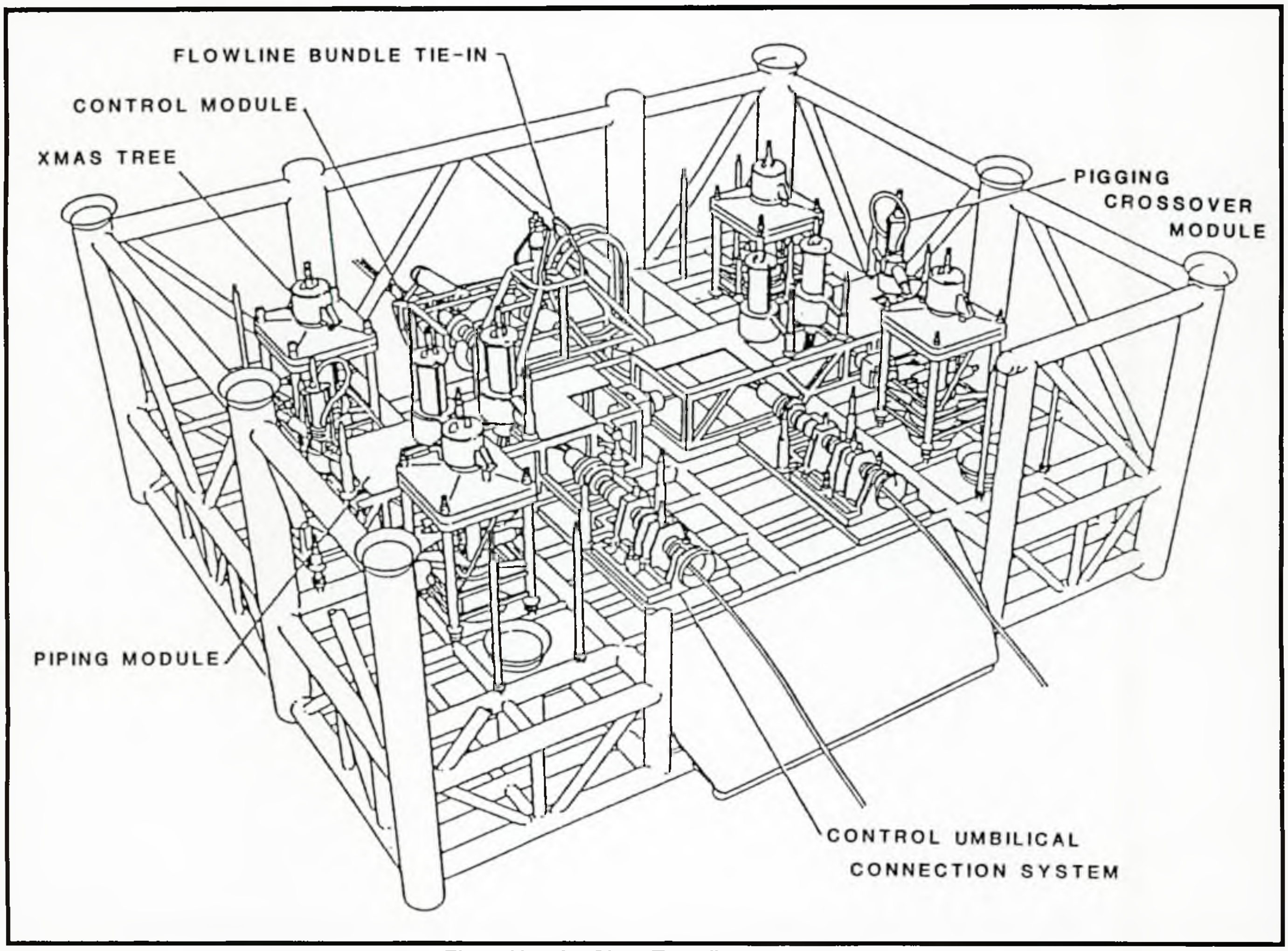

Fig 9: Norske Shell Troll field template

Highlander manifold (Fig 8) is an example of a subsea production system designed to be maintained by a diver. However, for diverless applications, special equipment must be developed in order that maintenance tasks can be undertaken by other means. A critical factor is that, by definition, all tasks must be pre-planned and a strategy evolved for coping with un-planned events.

Two main strategies have evolved; component replacement and modular replacement.[6,7] The proponents of component replacement believe that by only replacing the single failed component (valve, choke, control pod or seal, etc) minimum disturbance is caused to adjacent components which are performing satisfactorily.

Particularly important is the fact that component replacement rarely, if ever, requires the disconnection of multi-bore connectors and seals. The Shell/Esso UMC (Fig 3) and its forerunner the Exxon SPS are examples of subsea production system designs which allowed repair by replacement of individual components, by diverless means.

Packaging subsea components into modules permits the use of multi-bore connectors based on existing connector designs for Xmas trees and BOPs. The advocates of modularisation consider this to be advantageous because retrieval of the modules for service and repair can be accomplished utilising drill-rig technology which is well established, even in deep water. This type of approach is illustrated in the design of the Norske Shell Troll template (Fig 9) where all the equipment was designed to be retrieved by a drill-rig utilising drill-string.[8]

Table III: Comparisons of template/manifold size and weight

System	Number of wells	Dimensions			In air weight (t)
		L (m)	B (m)	H (m)	
UMC	9	52	42	15	2120
Highlander	12	43	18	9	1100
Troll	4 4 spare	40	29	9	1300

Common to all designs referenced above is their large size and weight, as indicated in Table III.

Subsea production systems of this type are generally designed and installed for the number of wells to be served, plus one or more spare slots as a contingency. In all cases this involves considerable pre-investment to outfit the template/manifold prior to installation. Size and weight generally results in installation being a significant offshore operation, a factor which further increases the level of pre-investment.

Most if not all of these large template/manifold designs were initiated before 1986 and were aimed at relatively large hydrocarbon reservoirs where high pre-investment was justified by high production rates, the need for efficiency and

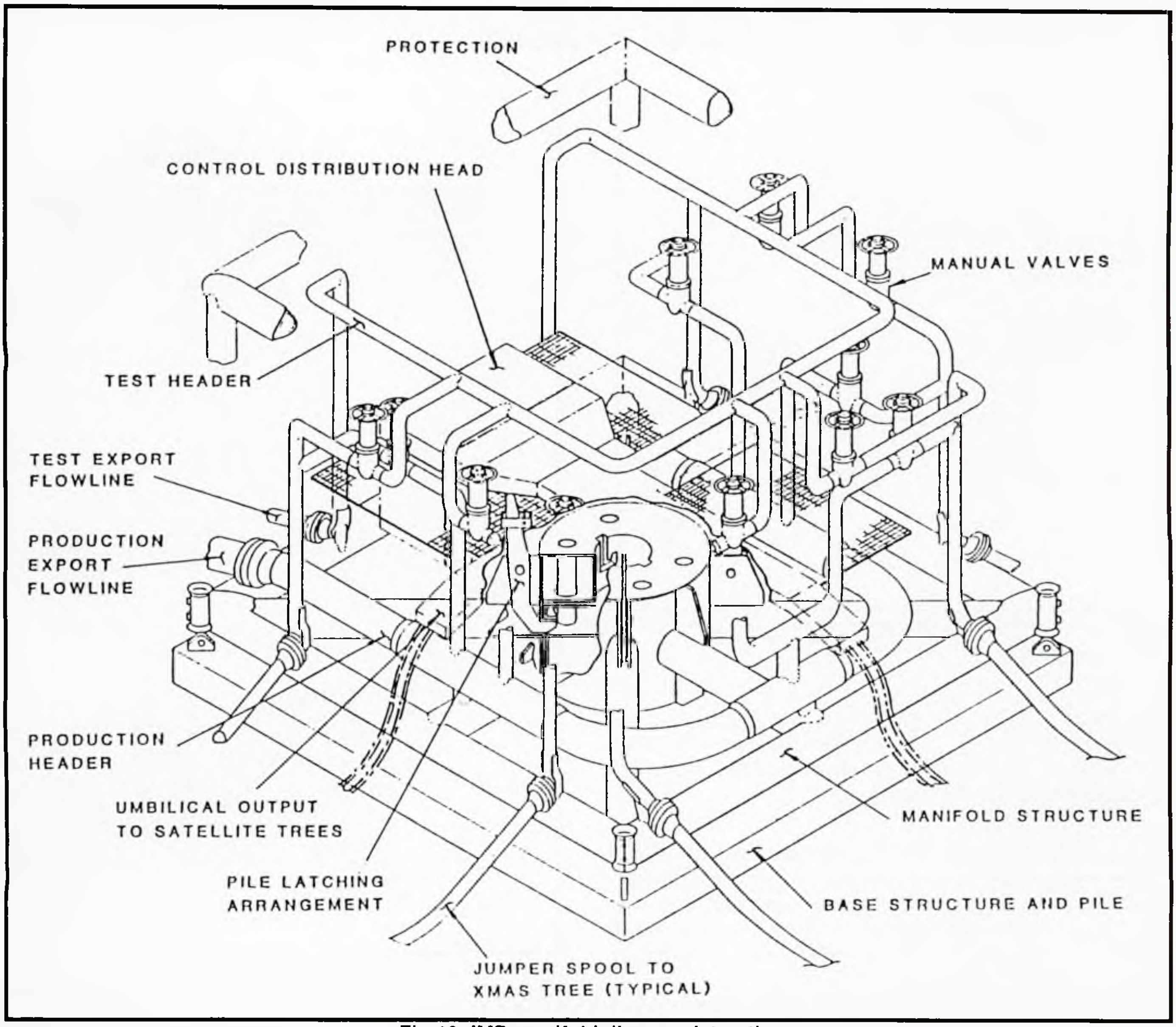

Fig 10: IMP manifold diver assist option

technical confidence in offshore operations in hostile environments.

Mini-manifold technology

The post 1986 era of lower oil prices, coupled with generally smaller reservoirs, has placed emphasis on the design of subsea manifolds which enable pre-investment and capital cost to be minimised.

The principles involved are presented in Fig 10, which illustrates an integrated mini-production manifold (IMP) design. In its simplest form, which is diver installed and maintained, the IMP manifold is 4.5m square, 3.5m high and weighs approximately 50t; it provides both production and test headers. All production control is achieved by valves, chokes, sensors and the control pod fitted to the Xmas tree (Fig 11).

The cluster arrangement, shown in Fig 12, allows all wells to be located within the anchor pattern of a drill-rig and so retains some of the benefits of template systems, but has the added advantage of providing sufficient clearance between Xmas trees to allow concurrent drilling and production without well shut-ins while the drill-rig is running heavy equipment. The cluster arrangement also allows production as soon as the first well is completed and thus offers cash flow benefits from early production.

DIVERLESS INSTALLATION AND MAINTENANCE OF MINI-MANIFOLDS

The mini-manifold concept can be readily adapted for deepwater by providing ROV maintainable components and remote flowline connection. A remote manifold based on the IMP design is shown on Fig 13; this relies on 'EDIPS style' intervention for maintenance of valves and control pods. The manifold is moonpool installable although the remote connector system requires a larger non-moonpool installable foundation structure.

The results of EDIPS work suggest that, for component replacement operation in *any* water depth, the ROV can be more cost effective than utilising divers. However, this would only be true in the case of the IMP system if the capital cost of

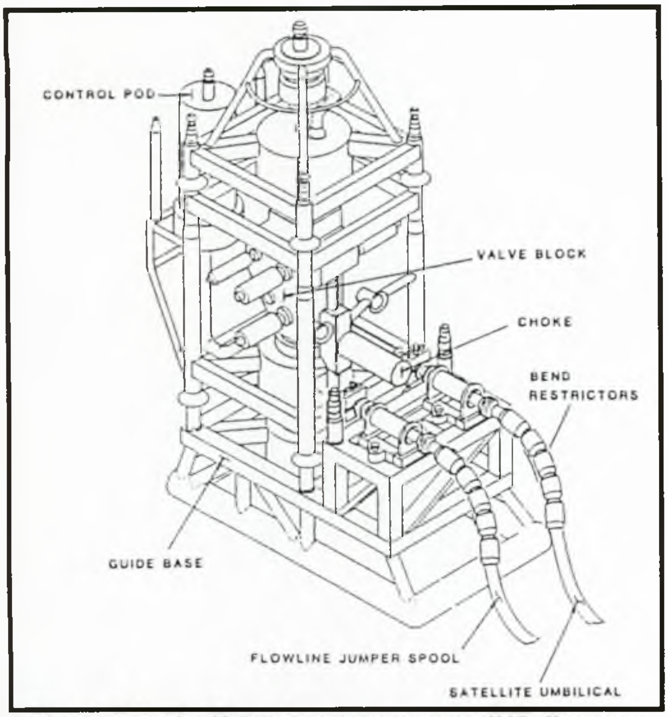

Fig 11: Satellite Xmas tree arrangement IMP diverless option

converting the basic diver maintained IMP, into a diverless maintained IMP, is low. This conversion has been considered in two stages: diver installed and diverless maintained; and diverless installation and maintenance.

Diver installed and diverless maintained

The IMP concept depicted in Fig 14 incorporates vertically mounted valves on the manifold which could be retrieved utilising the EDIPS control pod retrieval tool. The control pod and production choke mounted on the Xmas trees would also be configured for retrieval by EDIPS tooling.

In this configuration, the manifold increases in size from the 4.5m square of the diver assist version to 6.15m x 5.5m x 5.5m high, and weighs approximately 60t compared to 50t for the diver only version.

Diverless installed and maintained

This configuration is shown in Fig 13 and illustrates that provision of remote connection facilities for jumper spool installation causes considerable escalation in size and weight. The base structure is 9.2m square and weighs approximately 45t which, if installed with the manifold as a single unit, gives an overall size of 9.2m x 9.2m x 6.0m and an overall weight of approximately 95t.

The change from diver assist to diverless does incur an increase in capital cost, which is summarised in Table IV. It should be noted that only those elements of the IMP system which are affected by increasing levels of remote operation and maintenance capability are included. Costs common to both systems, eg flowlines, offshore operations or costs associated with the host facility, are not included.

Therefore, the costs shown in Table IV must be set within the context of the overall field development capital cost to reveal the limited impact on capital cost which the use of diverless technology would incur. If the host platform was situated 5 km distant from the subsea facility then overall costs for a mini-manifold development would be as shown in Table V.

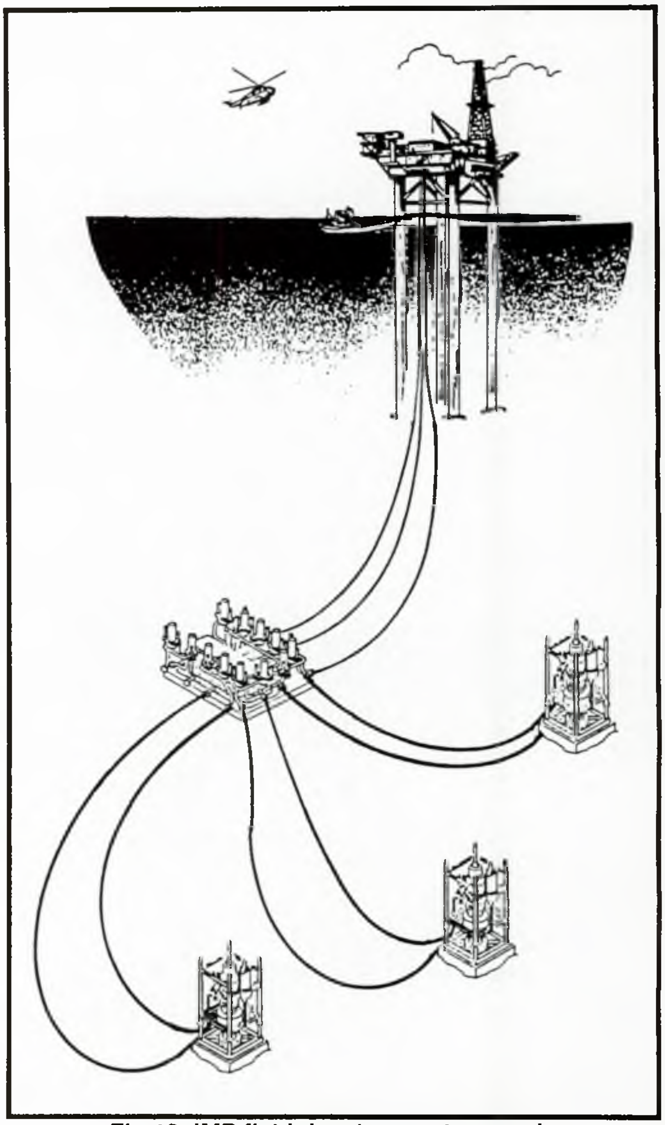

Fig 12: IMP field development scenario

It should be appreciated that although the costs presented in Tables IV and V are generalised and do not represent a specific development, they do illustrate clearly that subsea production systems in which mini-manifold technology is utilised will be very cost effective. The 'new' technology, ie the mini-manifold and associated equipment, represents a small proportion of the overall cost; drilling and completion, pipelines and Xmas trees represent over 80% of the development cost. The cost impact of adopting a totally diverless system, of £5–£6M, is therefore relatively insignificant within the context of the cost of a current overall field development in which intensive diver intervention is utilised. This limited increase in capital cost would be more than offset by reductions in operating expenditure.

JUMPER SPOOLPIECE CONNECTION

The use of a small, compact mini-manifold with conventional satellite wells clustered around it is rendered practicable by interconnections between the mini-manifold and the Xmas tree. In the scenario depicted in Fig 12, a total of 12 interconnections are required; six control umbilical jumpers and six

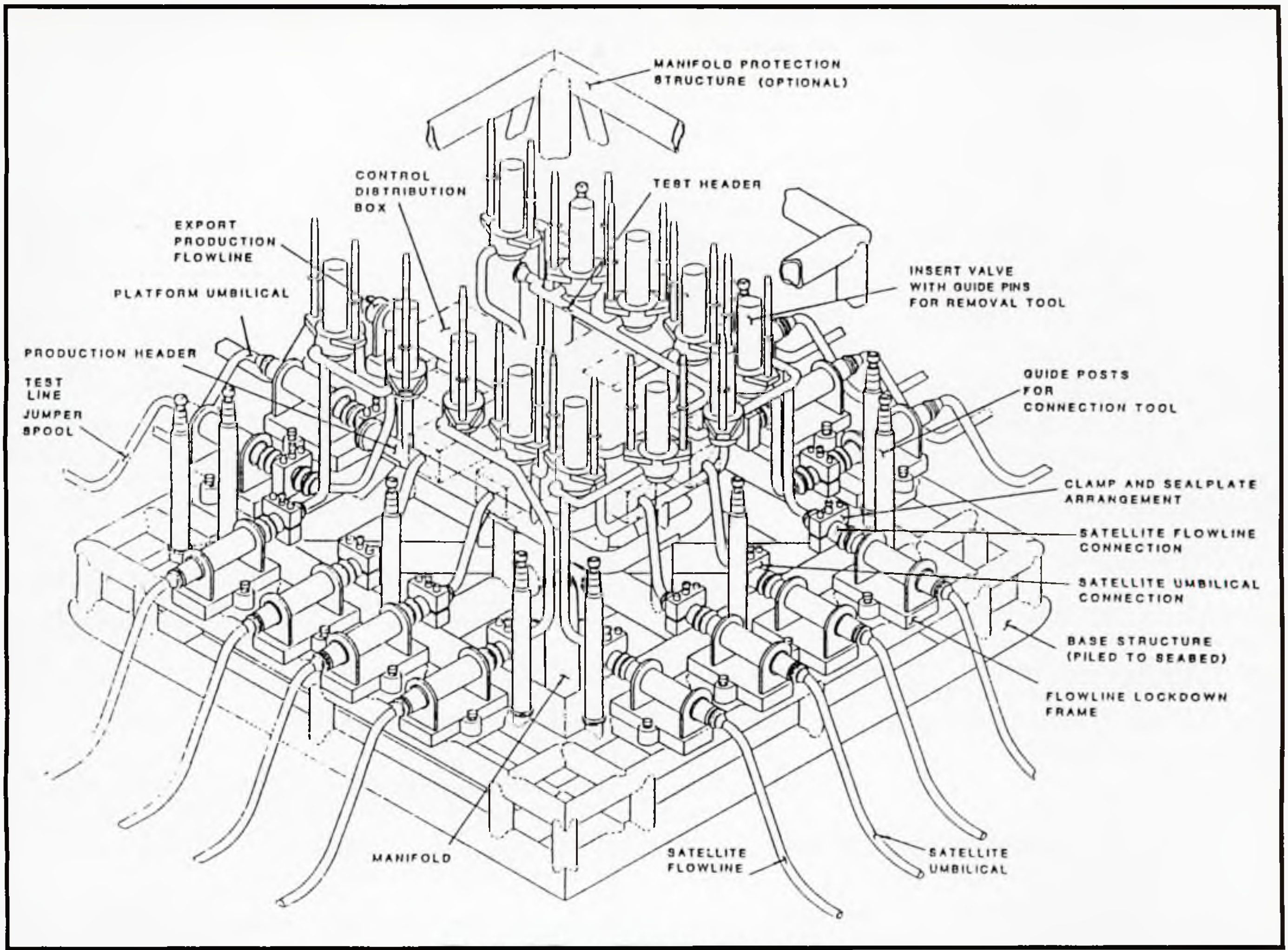

Fig 13: IMP manifold diverless option

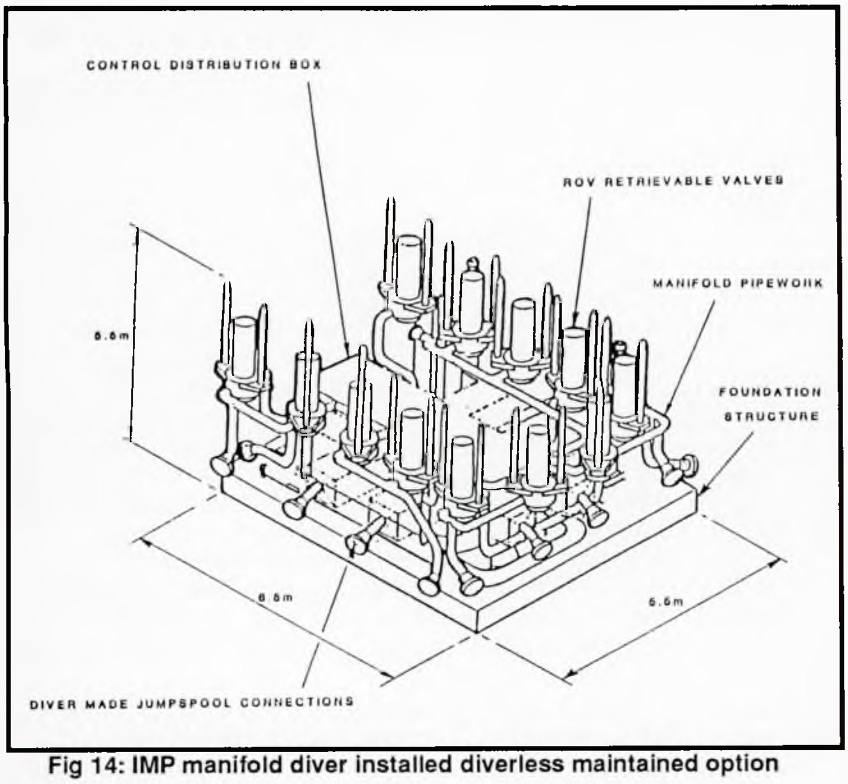

Fig 14: IMP manifold diver installed diverless maintained option

flowline jumpers. Although the estimated cost of making these interconnections is included in the installation cost estimate shown in Table V, the cost does not include for loss of drilling time while the interconnections are made, or for any loss of revenue incurred if the interconnections are delayed to accommodate drilling rig movements. In the analysis of whether or not a marginal field can be produced profitably lost time and lost production considerations can be significant.

The mini-manifold concept can minimise these installation-related costs because the manifold can be designed to a size whereby it can be installed via the rig moonpool. For this design a single pile foundation is used; the drill-rig can run a temporary guidebase, drill and grout the pile and install the manifold within two days. The critical aspect with regard to maximising the economic benefits of the mini-manifold concept is, therefore, the installation of the interconnecting jumper spoolpieces between the manifold and the Xmas trees, while minimising interference with the drilling programme.

Mini-manifold technology is now being applied in the North Sea, utilising diver intensive installation and maintenance techniques. Shell/Esso's Osprey field, due for installation in 1990, is the most recent example. This and earlier cluster well developments provide confidence that diver based jumper spoolpiece installation procedures are cost effective.

As part of work on the Esso diverless maintained cluster (DMaC) programme, concepts for diverless installation and connection of these interconnecting spoolpieces are being developed, based on the EDIPS design philosophy. These will facilitate spoolpiece installation using the drill-crane and drill support ROV. With these techniques installation could be achieved with little or no additional cost over that incurred for drilling the wells, since installation tasks will be completed by equipment and personnel already costed as part of the drilling programme. This approach not only saves capital cost but, because drilling and installation activities are concurrent, individual wells can be brought on stream at the earliest possible opportunity, thus maximising cash flow.

There is confidence that these ROV based spoolpiece installation techniques can be efficiently undertaken as a result of the successfully completed prototype tests on the EDIPS tool package to replace control modules. The current Esso DMaC programme utilises the same philosophies and principles in the design of a tool package for choke retrieval, which is currently planned for prototype testing in 1990/1991, and for the design of ROV operated equipment for jumper spoolpiece installation which is currently in progress.

Table IV: Comparison of IMP manifold physical and cost features

	Diver assist IMP	*Diverless maintained IMP*	*Diverless installed and maintained IMP*
Size L x B x H (m)	4.5 x 4.5 x 3.5	6.15 x 5.5 x 5.5	9.2 x 8.2 x 6.5
Manifold air weight (t)	52	60	105
Capital cost £M			
6 off Xmas tree	4.50	6.00	6.00
1 off manifold	0.38	0.51	0.64
6 off control pod	1.38	1.62	1.62
6 off control and flowline spools	0.22	0.33	2.37
1 off control distribution box	0.17	0.17	0.27
Tooling	0.50	0.70	0.90
Total	**7.15**	**9.33**	**11.80**

Table V: Cost of six well mini-manifold prodution system (excludes any costs at host facility)

Activity	*Cost £M*
Drilling and completion (6 wells)	20
Pipelines and umbilical (material and installation)	4
Production system capital cost (diver to diverless)	7–12
Production system engineering and installation (diver to diverless)	5–6
Total	**36–42**

APPLICATION OF DIVERLESS MAINTENANCE AND INSTALLATION PROCEDURES IN SHALLOW WATER

Surface handling

The EDIPS programme was originally targeted at deepwater applications where there was little option other than to employ remote maintenance techniques. In that context it was believed that the surface handling system was not a technical issue but would be more an economic issue governed by three major considerations as follows:

1. weather conditions under which maintenance must be achievable;
2. type of vessel available as surface support for the ROV;
3. type of handling systems available.

The possibility highlighted by the EDIPS programme as a result of successful prototype trials of the control pod replacement tool, was that the system was so effective it could be less costly than diver intervention, even in shallow water.

In shallow water, ie water depths in which ROV maintenance technology has to compete with existing diver-based technology, the cost and availability of suitable handling systems and surface support vessels will be a factor when considering ROV based maintenance techniques. This is because many potential surface support vessels (SSVs) are already fitted with systems for running and retrieving diving bells and associated equipment. For those same SSVs to support ROV and tool packages in shallow water, a means of launch and recovery of packages of 3.5–5t in air (ROV, tool package and cursor weight) would be required. The system must have weather tolerance similar to existing deployment systems at a cost and availability which is comparable with the cost and availability of existing diving bell and equipment handling systems. Transportable, readily fitted systems for ROV launch and recovery are available, however further investigation is required to extend their capability in order that they may handle a mass of up to 5t in operational conditions equivalent to those in which a diving spread can undertake similar tasks.

CONCLUSIONS

Evidence from subsea production systems currently operating in the North Sea indicates that the requirement to repair subsea equipment is, in practice, infrequent. The design of maintenance and repair systems should therefore emphasise factors which promote operational simplicity and low cost, rather than aiming for operational efficiency.

The EDIPS system has been developed with these factors as key design inputs and successful prototype tests have proven the operational effectiveness of the approach. The system is not significantly affected by water depth, from shallow water down to 1000m, and in combination with mini-manifold technology offers the real possibility of economic development of deepwater hydrocarbon accumulations. The effectiveness of the designs will extend into the future since they are readily adaptable to new technologies for enhanced recovery, including multi-phase pumping.

Mini-manifold technology requires the connection of control umbilicals, flowlines and perhaps several jumper spoolpieces on the seafloor; within diver depths, make-up of these connections is proven technology. Technology for undertaking these connection tasks without diver assistance is being developed following the principles established in the EDIPS programme. Successful demonstration of this technology will represent a major advance in further extending the operational effectiveness of ROV based intervention procedures.

In shallow water the demonstrated speed and effectiveness of ROV intervention, and the safety advantages remote intervention offers, provide a realistic option to diver based intervention procedures without a significant increase in overall field development capital expenditure.

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Discussion

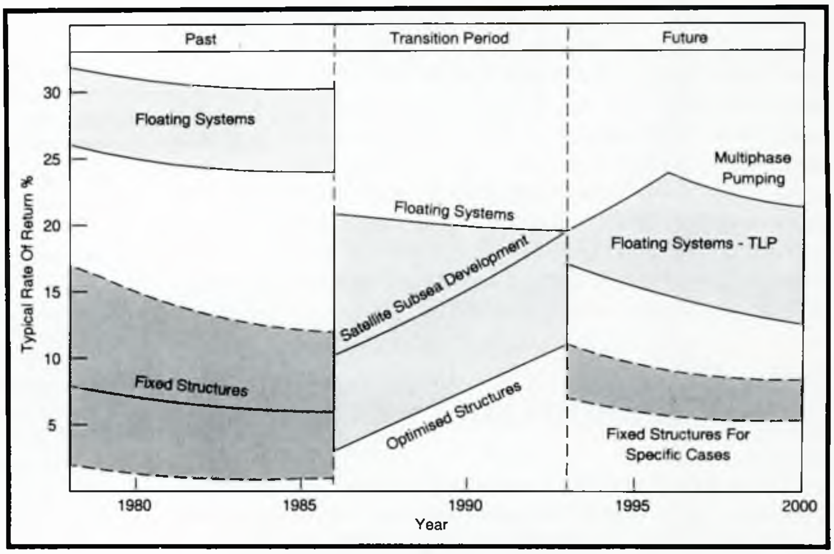

Fig 1: Offshore production trends

S M Adamson (Fuel Subsea Engineering Ltd) Mr White's paper has focussed on the changing manner in which offshore hydrocarbon accumulations are produced. I fully concur with the views expressed in the paper and would like to place the proposed use of ROV maintained manifold/cluster well arrangements within the context of trends in offshore production system developments (see my Fig 1).

Until the oil price crash in 1986, offshore fields were developed primarily from fixed platform structures with comparatively little use of subsea production systems. Where large scale subsea systems were utilised, these were either associated with floating production systems or as satellite tie-backs to existing fixed structures; BP Buchan and Hamilton Argyll are examples of the former, and Shell UMC/Cormorant and Texaco Highlander the latter.

We are currently within the transition period (see my Fig 1) in which much more emphasis is, of necessity, being given to the economic production of small hydrocarbon accumulations and, internationally, to the development of deep water accumulations (eg Brazil, Gulf of Mexico and Norway). During this period less emphasis is being given to the deployment of new fixed structures with greater emphasis to:

1. subsea production systems tied back over increasing distances to an existing host facility;
2. application of stand-alone floating/subsea production systems.

Where fixed platforms can be justified these are generally of optimised lightweight design, with 'lightweight' topside facilities.

It is this increasing trend in the use of subsea production systems, and the emphasis now being placed upon the development of multiphase pumping technology, which will enable simple, subsea systems to provide the basis on which future small accumulations can be economically produced. Therefore, I confidently envisage that such developments will centre around the type of clustered well/manifold configurations presented in Mr White's paper.

During the transition period referred to in my Fig 1, these manifold/clustered well systems could be maintained either by diver or ROV, and would export to an existing production infrastructure or to a new production platform; either lightweight fixed, or floating.

By installing 'marinised' multiphase pumps on the manifold, the possibility exists to export produced hydrocarbons to more distant offshore production platforms and, potentially, over great distances directly to shore-based processing facilities.

This latter scenario offers great potential for the future production of hydrocarbons in remote, deep water locations where no existing production infrastructure exists. The ROV based maintenance systems described by Mr White would be employed.

In conclusion, the concept of clustered subsea wells tied into manifolds can therefore be utilised on most future oil production developments and could, in many cases, obviate the need for costly offshore processing facilities. Therefore, the following questions can be posed:

1. What is the maximum distance over which multiphase products can be pumped?
   Multiphase pumps are being developed to pump produced hydrocarbons with very high gas/oil ratios over long distances; booster stations could be employed if required. Areas that need to be addressed include:
   a. power supply from shore (probably dc if distances are great);
   b. fluid behaviour in long pipelines;
   c. corrosion due to water settlement in low velocity/large diameter pipelines;
   d. need for special materials and/or coatings;
   e. chemical inhibition for hydrates and wax formation;
   f. sand transportation.
2. Will subsea separation be required?
   Subsea separation has been considered for over 10 years primarily because of the lack of availability of multiphase pumps. Multiphase pump technology is developing at a rapid pace, and such pumps are now being used offshore, albeit not subsea. Therefore, subsea separation is, under most circumstances, unlikely to be required in the future.
3. Do production platforms have a long term future?
   Platform based production facilities will continue to be utilised in relatively shallow water, and some special applications in the future. However, on the assumption that it is improbable that any new giant offshore fields will be discovered, most discoveries in frontier regions would be unviable at anticipated crude oil prices if platform based infrastructures were required. Under such circumstances, it could be argued that platforms do not have a long term future; direct production to shore utilising clustered well/simple manifold/multiphase pumping could supersede platforms in such areas.
4. Can technology developed for shallow water be applied to deep water?
   Mr White has confirmed that it can. The utilisation of ROV tooling systems to a simple cluster well/manifold arrangement can render some of the large, costly subsea template/manifold systems developed in Norway during the early 1980s unnecessary.

J White (Fuel Subsea Engineering Ltd) I agree with Mr Adamson that the technology described in the paper is compatible with the concept of multiphase pumping and that multiphase pumping has great potential as a means of developing smaller offshore fields. Conceptually subsea multiphase pumps have the capability to transport unprocessed hydrocarbons over long distances, utilising booster pumps to export live crude direct to land based processing facilities, thus obviating the need for either platform or vessel based process equipment. The major concern about multiphase pumps, expressed by some oil companies, is the perceived complexity of a subsea pumping station and the operating costs of in-service maintenance of the pump and associated equipment. Currently intervention on a subsea pump is predicted to be a biennial requirement but this could be achieved in a very cost effective manner utilising ROV based maintenance concepts, described in the paper, whilst the ROV is undertaking other routine maintenance tasks, eg pipeline surveys.

P Metcalf (Fuel Subsea Engineering Ltd) Mr White's excellent paper clearly identifies the technological advances made in ROV tooling systems and their relevance to the evolution of subsea production systems in the future. The prototype testing of these tooling systems demonstrates their practicality and provides the necessary track record to ensure technical acceptance by the operator.

There is no doubt that in the foreseeable future North Sea development will concentrate on the development of small, marginal reserves with a strong emphasis on the use of subsea completions. With this in mind the commercial future for ROV maintenance must lie in providing a cheaper alternative to divers.

Today's financial constraints might lead certain small operators to baulk at buying tooling packages for themselves particularly if field life is short and hence the level of usage of such tools is small. Indeed such operators might prefer to accept higher maintenance costs that can be paid for out of revenue rather than increased capital expenditure. Their ideal goal might be for such packages to be available off the shelf from a number of ROV operators so that competitive bids could be sought for maintenance activities as required.

In the light of experience gained to date would Mr White care to comment on the place of standardisation of ROV tooling packages and, more particularly, their interfaces with subsea production hardware in achieving this goal, and what steps might be taken to encourage small operators to take advantage of current ROV tooling system developments?

J White (Fuel Subsea Engineering Ltd) Attempts are being made to define common interfaces between subsea production equipment and ROV/diver deployed intervention equipment. These efforts include specification of interface features as part of proposed revisions to API 17-D, Section 921. However, I believe that these interface specifications relate mainly to override devices, either mechanical, or hydraulic utilising a hot stab, and not to retrieval of major components. The ROV tooling systems described in the paper were designed to retrieve major components, eg chokes, valves and control pods from all the major suppliers of such components. Nevertheless some mechanical interface features would have to be modified to interface with a particular valve, choke or control pod. These modifications are simple and could generally be accomplished during mobilisation of the equipment. Whilst there would seem to be a *prima facie* case that standardisation would offer cost benefits some studies have shown that this is not necessarily true. The cost disadvantages of accepting a design which is less than ideal can outweigh cost benefits achieved by accepting a standard design.

With respect to encouraging smaller operating oil companies to utilise current ROV tooling developments, the key criteria are cost and availability. ROV operators now offer simple low cost tools for operating mechanical, or hydraulic overrides, cleaning, and some inspection tasks. It is the responsibility of designers, hardware suppliers and ROV operators to ensure that the smaller oil company is made aware that there are cost savings to be made by designing their subsea installations to be suitable for ROV intervention.

I am sure that most of the good engineers and managers in such companies are already aware that many tasks previously undertaken by divers are now within the scope of simple ROV equipment and can be considered routine ROV operations.

The technology developed by FUEL and ESSO as part of the EDIPS programme clearly extends the capability of the ROV beyond that which is commercially practised at present. However, it has been ESSO's policy throughout the EDIPS programme to make the technology available to industry by ensuring participation of design contractors, like FUEL, and offshore service contractors, like 2W (now Rockwater). Smaller oil companies can access this diverless technology via these contractors.

I M Barrett [IMBAR (Consulting)] I would like to make two observations:

1. Without attempting to prejudge the findings which will appear in the report of the inquiry into the Piper Alpha disaster, it is almost certain that industry will need to install what may be called 'inventory splitting oil line sectioning devices' on high pressure gas and spiked crude lines. Although some of these may be platform mounted, it is likely that many will have actuators and equipment which will require intervention by such ROVs and similar accessories to those which we have heard about today – this will undoubtedly present an opportunity for development and business in the future.
2. In the light of the mounting experience with various devices for ROV intervention operations, there is a case for identifying and establishing standard and preferred methods of conducting some of the basic operations such as engaging, reacting, torquing, extracting, etc.

The emergence of such guidelines and standards will assist in obtaining the confidence of users in this subsea technology.

J White (Fuel Subsea Engineering Ltd) As I said in response to Peter Metcalf's question on standardisation API is drafting a code for those intervention tasks which are already established as routine ROV tasks. As we stretch ROV intervention into new areas, preferred ways of achieving intervention tasks may emerge but at present there is no commonly accepted method for ROV retrieval of major components of a subsea system. Therefore, it is likely to be a long time before standards can be agreed and designs will probably remain operator- or field-specific for some time. There is some evidence that in many cases a standard solution may not necessarily be the most cost effective solution although operational experience with similar equipment will clearly generate confidence in potential users. Establishing confidence in operational effectiveness was one reason why ESSO took the EDIPS programme through to full scale prototype trials in 150m of water.

M T Usher (Consultant) Was the reliability of the ROV taken into account? In a design which demanded diverless intervention, on an infrequent basis, where a hired ROV was probably brought into service, possibly at short notice and after a period of inactivity, high reliability is important. Confidence in the subsea equipment must therefore depend on achieving such a good performance from an ROV available 'on the shelf'. Does the author have any figures to support this?

I would also like to bring the author's attention to the need for standardisation of the interfaces with the ROV which would further increase confidence by providing alternative sources for ROVs.

J White (Fuel Subsea Engineering Ltd) I agree with Mr Usher that ROV reliability is an important factor in the reliability of the overall maintenance system. In the case of the EDIPS programme this issue was addressed by requiring the maintenance equipment to be compatible with most commonly available work class ROVs. In practice the EDIPS equipment will readily interface with seven different work class ROVs. This means that the client oil company has several sources of supply of ROV based maintenance, and proven in-service ROVs can be used; there is no requirement to utilise a special 'on the shelf' ROV.

A Burnett (Offshore and Marine International Services) On looking at the title of the paper, it was hoped that the subject to be addressed would cover a reasonably wide scope involving a number of different ROV/deep water possible locations worldwide.

When the paper was read in more detail, and especially the paragraph headed 'Conclusions', it was evident that the North Sea underwater market was solely chosen for most of the main detail and arguments outlined in the paper itself. This was disappointing, particularly in view of the fact that deep water markets, outside the North Sea itself, are now presenting suppliers with an increasing market share over and above that obtainable from the somewhat limited North Sea deep water market itself.

The present low frequency use of maintenance equipment in the subsea environment (presumably in the North Sea) was mentioned, giving rise to a revised design philosophy based on operational simplicity, with recourse to specialist staff (p220). This concept gives rise to several important questions.

1. In the deep/deeper waters, where reduced access is presumed for maintenance purposes, will underwater fouling occur thus making access when required both difficult and possibly impractical?
2. In some areas of the world, underwater (seabed) water currents are considerably in excess of the figure of 0.75 kn referred to (p221). Will the concept outlined still be valid for these high seabed water speeds of 3–5 kn found in various deep water areas around the world?
3. Two 'trips' subsea to exchange out a single component was mentioned for the EDIPS system (p221). At deep water sites of 1000–4000m, now found off Brazil and elsewhere, what will be the cost advantage of having two 'trips' for component exchange purposes?
4. At 1000–4000m water depths, the umbilical cable attached to the ROV system for maintenance purposes will be not only extremely long and heavy but will also produce oscillating and harmonic motion characteristics at the ROV itself, making accurate/detailed work programmes at these water depths extremely difficult. How will these factors be overcome?
5. With these envisaged infrequent maintenance trips to change single components in deep water, all items connected with the retrieval systems must work first time. How can this be guaranteed with so few maintenance trips at any one site? The retrieval equipment/system must always work when needed otherwise all cost advantages will be lost by the cost of the back-up service needed to remedy the faulty retrieval work programme.
6. The conclusion concerning possible use of such ROV systems in competition with or in lieu of diver based intervention procedures in shallow water markets, not necessarily confined to oil/gas scenarios, was identified by IFREMER over a decade ago. Why has comparatively little progress been made in these directions over the last 10 years or so?

J White (Fuel Subsea Engineering Ltd)

1. The problem of fouling by marine growth is probably more severe in shallow water than in deep water. The docking and acquisition systems of the maintenance equipment are designed to accommodate considerable fouling. In particular the docking cones are powered together in both the horizontal mode (choke/valve retrieval tool) and in the vertical mode (control pod retrieval tool). In addition high pressure jetting for cleaning would be available from the ROV during its initial inspection dive if fouling was severe.
2. Several of the questions raised by Mr Burnett relate to the use of the diverless maintenance equipment described in my paper in water depths of 1000m and greater. If the paper gives the impression that the ROV based system is designed for relatively shallow water then this is an error. The equipment is designed for use in 1000m water depths, has been tested with a full scale prototype in 150m and the results extrapolated to 1000m operation. Extension of the system into deeper water is not limited by the maintenance system but by the delivery vehicle, ie the commercially available ROV. I am not an expert on the deployment of ROVs in deep water but I believe the main problems will lie in the drag forces that a 4000m umbilical will impose on the ROV, limiting its manoeuvrability. This problem can be addressed by improved umbilical design and by use of clump weights to isolate a short section of the umbilical close to the ROV. This technique is used in current ROV operations, in specific circumstances, and would have to be available for routine ROV observation tasks in deep water, as well as for deployment of maintenance equipment.
3. The selection of a two trip operation for component replacement was made to ensure that the tooling was as simple as possible. The rationale for that choice was that intervention would be infrequent and, because components are generally reliable, very few components would be changed out during any one maintenance operation.
   The total cost of a maintenance operation includes the time and cost of mobilising, and demobilising the vessel, ROV and tooling.
   This time, and the possibility of delay due to faulty maintenance equipment, is increased the more complex and specialist the maintenance equipment becomes. If the cost benefit assessment of the maintenance operation includes these activities it becomes apparent that the effect on overall maintenance operation, time and cost, of the ROV spending time on two additional trips to the subsea worksite is marginal. Even in 4000m of water the total on site time for two trips subsea, including the component replacement operation, will be less than 24h, once the surface support vessel is on site.
4. I concur with Mr Burnett's point that infrequently used maintenance equipment must work first time and with the minimum of specialist onshore maintenance whilst it is in

storage. That thought was one of the reasons why the system was designed to work with most commercially available ROVs; the delivery vehicle is a vehicle involved in current operations, not one retrieved from mothballs. The equipment is technically very simple and robust. It is designed to be mobilised by technicians familiar with ROV systems and equipment but without specialist knowledge of the maintenance equipment. Finally, as the prototype trials demonstrated, the equipment can be operated by any competent ROV pilot, it does not require special ability or training. These deliberate design choices were made to give the system the best possible chance of working first time.

5. Mr Burnett's last point that IFREMER had identified the *potential* for ROV system use in diver depths 10 years ago but that little progress has been made so far has no factual answer, however I can offer a personal thought.

   Ten years ago diverless equipment had a poor reliability record, as I indicated in the paper, and as a result systems designed to be maintained by diverless means often incorporated considerable redundancy with a commensurate increase in cost and complexity. The concept of diverless maintenance was, therefore, linked with complexity and high cost. It has largely been through R&D projects, like EDIPS, that simple cost effective designs for diverless intervention have been developed; these developments are relatively recent and have yet to find commercial application. Over a similar time period the range of tasks routinely undertaken by the ROV has also developed, particularly in drill support activities. However, it is only relatively recently that the ROV has established a track record as a reliable means of accomplishing subsea work tasks. It has also taken until recent times for subsea production equipment to demonstrate that it can operate with very high availability so that redundant systems are no longer required; in fact redundancy is now often strongly discouraged. The combination of these developments will lead to cost effective diverless systems but the process will probably be evolutionary rather than revolutionary.