Oil Spill Containment, Remote Sensing and Tracking For Deepwater Blowouts: Status of Existing and Emerging Technologies

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Final Report

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Executive Summary

This report evaluates the technical hurdles associated with the remote sensing, tracking, containing and recovering oil released from deep water blowouts. An analysis of oil-spill containment and recovery technologies that will facilitate overcoming these technical hurdles is provided.

The report presents an overview of deepwater well control barriers that are used to develop deepwater blowout scenarios. A critical component analysis and consequence analysis follow these scenarios. A patent search of deepwater blowout control technologies was performed and the resulting patents evaluated to assist in the evaluation of potential deepwater blowout countermeasures. Although seven patents are identified that warrant further investigation, the report concludes that undersea recovery of oil from a deepwater blowout is unlikely for subsea releases. The best options for subsea blowout spill control seem to be technologies to facilitate vertical intervention to contain the flow using well control techniques, and technologies for speeding the process of natural degradation of the released oil using dispersants applied at the wellhead.

A Multi-Purpose Deepwater Crawler concept has been developed and is presented to overcome most of the identified technical hurdles. It would have the ability to approach the blowing well and characterize the flow, assist with the manipulation of heavy objects at or near the wellhead, manipulate BOP system overrides, and apply dispersants at the blowout source.

Additional technologies for potential subsea application to deepwater blowouts include the use of enhanced CCD cameras for blowout imaging, acoustic and autonomous buoy systems for plume tracking, and towed plume detection systems.

Once the oil has reached the sea surface, existing spill response equipment and methodologies can be used to contain and recover the oil. Since deepwater sites are typically remote from land, the use of spacecraft based imaging systems for spilled oil surveillance has the potential to overcome the fuel capacity limitations of fixed wing aircraft and helicopters.

Priority research areas for funding by MMS should include:
- Development of methods to model and predict plume dynamics, including the collection of data to validate the models
- Participation in deepwater blowout simulation tests to allow the testing, evaluation and continued development of technologies for blowout imaging, subsurface plume detection, and methods for the application of dispersants at the blowout source.
- Development of the Multi-Purpose Deepwater Crawler concept for intervention near the seafloor

1.0 Introduction

This study, authorized by Minerals Management Service Contract No. 1435-01-98-PO-15135, summarizes the status of existing and emerging technologies for oil spill containment, remote sensing and tracking for oil released from deepwater blowouts.

This report examines the problem of oil released from well blowouts in deep water and provides a review of past solutions and existing technologies. It identifies those technologies that have the potential to provide rapid mobilization and deployment for deepwater blowout containment and countermeasures. It does not address deepwater well control.

With new royalty relief, deepwater drilling and production operations have increased dramatically. As the industry advances into deepwater exploration, the risks of blow out increase, due to difficulties related to kick detection and control procedures under deepwater conditions. There is very little blowout experience in deepwater from which to draw when evaluating countermeasures.

Some research and design work occurred in the early 1980s after the 1977 oil and natural gas blowout on the Phillips Petroleum Co. ABravo≅ production platform in Norway and the 1979 Ixtoc I blowout in the Gulf of Mexico. The Ixtoc I, the largest known blowout event, occurred in 160 ft water depth. The “Sombrero” oil collector system was designed, built and installed by Brown and Root, Inc. for Pemex in an attempt to contain the oil flow from this blowout while relief wells were being drilled to kill the blowout. There was no advance design or planning for this system which was designed, built and installed in less than three months. The “Sombrero” generally was considered a failure as it recovered a very low percentage of the oil released, and was later removed after it suffered a structural failure.

The last patent for an offshore blowout recovery system was issued in 1984. In spite of numerous theoretical and model tests studies following the Ixtoc I blowout, no method had been identified as a satisfactory solution (B&R, 1985). This might have been due to the concentration on solutions requiring a high capital outlay for a low probability event; and because blowout scenarios vary, there is not a single subsurface collection device applicable to all scenarios.

For this reason we assembled a team of experts in blowout control, deep water intervention, and oil spill countermeasures to evaluate and develop innovative technologies that will facilitate the containment and recovery of oil spilled from deep water blowouts. This team included PCCI, which has one of the largest group of full time marine oil spill engineering professionals supporting industry and government; NOREN, deep water oil recovery equipment experts; and Wild Well Control, Inc. which specializes in blowout control.

A draft report addressing deepwater blowout well control was prepared by the International Association of Drilling Contractors (IADC, 1998) in conjunction with the Offshore Operators Committee. This draft was reviewed prior to initiating our work and we have used the same definitions for water depths relative to well control, i.e.:

• Conventional	1,000 - 3,000 ft.

Deepwater	3,000 - 6,500 ft.
Ultra Deepwater	6,500 - 10,000 ft.

The emergency response section of the IADC report focused on blowout contingency planning, vertical intervention, relief wells, dynamic kill considerations, and spill control.

2.0 Approach

The behavior of fluids released in deep water, under high hydrostatic pressure and low ambient temperature, are likely to be fundamentally different than for shallow water. A shallow water release of oil and gas from a high pressure formation, and with a high velocity, results in turbulent mixing of the gas, oil, and water, with the mixture quickly transported to the surface by the expanding gas under ever decreasing hydrostatic pressure (See Figure 1).

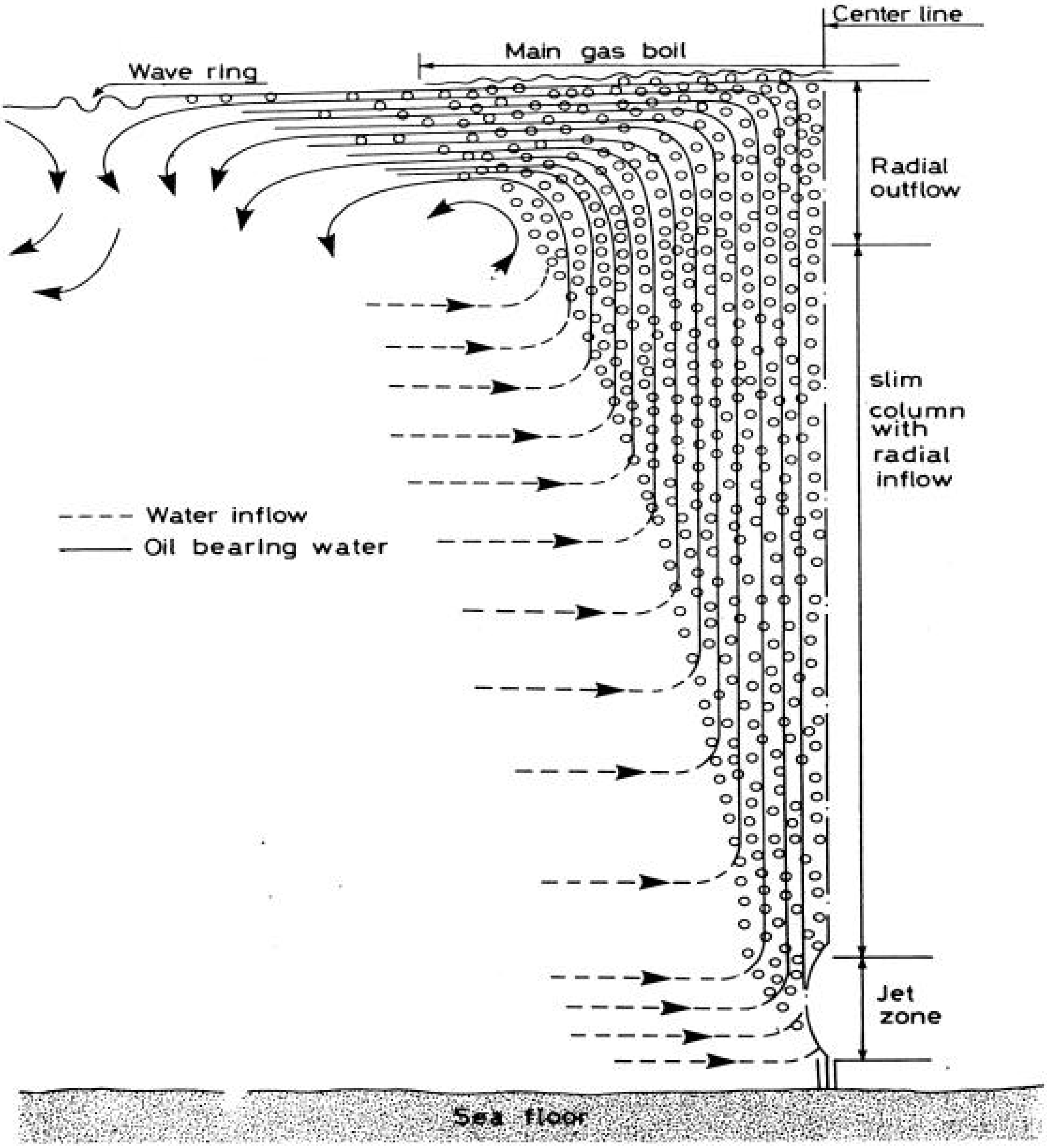


Figure 1 - Shallow Water Blowout Plume

The ocean water at many deepwater sites is greatly stratified with varying salinity, temperature, and currents. There is little historic data for deepwater well blowouts; therefore, considerable theoretical research on the behavior of deepwater releases has been undertaken and is summarized in an unpublished paper by Alan, et. al., 1997. The research raised important questions including:

- There has been speculation that solid methane/water hydrates might form from some blowout gases. The formation of neutrally buoyant hydrates might eliminate the driving buoyancy of the rising plume. Questions remain: Under what conditions are solid hydrates formed? If this occurs, what becomes of the oil?
- Even without hydrate formation, oil entrained in sea water from a blowout may reach a "terminal" layer in a stratified fluid (temperature and salinity differences) at which point the plume becomes neutrally buoyant and ceases to rise. (Rye & Branvick, 1997) However, the oil may finally arrive at the sea surface due to the considerably smaller buoyancy caused by the gas hydrates and oil driving the rise of the oil-gas-water plume. Figure 1 illustrates the relationship between depth, ambient temperature and hydrate formation from a model simulation of a blowout at 1200 m depth. (Reed et.al., 1999).
- The potential exists for phase separation or segregation as shown in Figure 2. One of the theories for ultra deepwater is that the oil plume will deteriorate. This can be expected because the gas and oil mixture exiting from a blowout is assumed to flow as alternating slugs of gas and oil in a process that disperses the oil into fine droplets (Topham, 1975). These oil droplets will quickly disperse and be displaced from the gas plume in the presence of unfavorable salinity and temperature gradients and strong horizontal currents which may be common at deepwater depths. This may result in dispersion of oil away from the plume with only a small gas boil reaching the surface (Westergaard, 1987).

The high hydrostatic pressures at depth (See Table 1) will aid in choking any flow from potential blowout points. This seawater head acts as a constant backpressure which may provide both benefits and drawbacks for the control of oil from blowouts. Benefits include the assistance in reducing the flow that the backpressure would provide. This backpressure will slow the flow rate, and in some cases exceed the reservoir pressure in ultra deepwaters. In these cases blowouts are likely to only occur below the seafloor, with no resulting oil release to the ocean. However, by limiting the production rate, the backpressure may inhibit collapse of the well (Neal Adams Firefighters, Inc. 1991).

Depth (ft)	Pressure (psi)
1,000	460
3,000	1,351
6,500	2,910
10,000	4,469

Table 1 - Example of High Hydrostatic Pressures in Deep Water

Our work was performed in successive steps with due consideration of the uncertainties described above. Section 3.0 describes barrier mechanisms and subsea drilling equipment designed for well control. Wild Well Control then used first hand experience to develop blowout scenarios for the drilling, completion and workover phases of subsea oil production, and for producing wells, in Section 4.0. Section 5.0 provides a matrix of potential blowout exit points describing the relative likelihood of each exit point being the most probable failure point. Section 6.0 gives a ranking of the consequences of blowouts from each of the probable exit points. With the information developed, Section 7.0 describes the technical hurdles anticipated in sensing, tracking, containing, and recovering oil released from a deepwater blowout. A patent search was then performed in both Norway and in the U.S. for blowout containment devices. Over sixty patents applicable to blowout containment and recovery were evaluated for potential

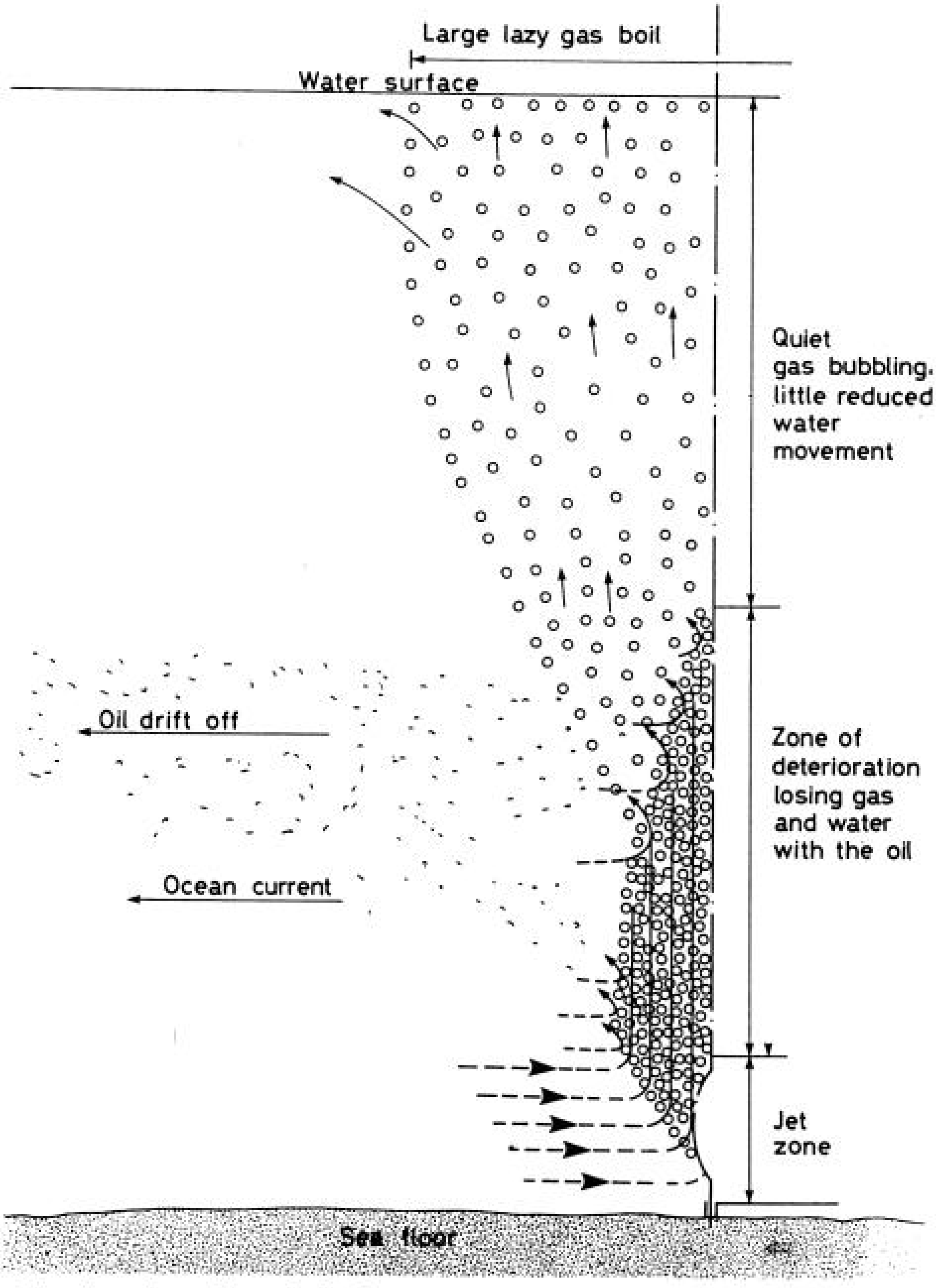


Figure 2 - Deteriorating Plume as Might be Expected in Deepwater

modification and use in deepwater and ultra deepwater. Section 8.0 describes the methods used to obtain the patents, a description of the patented device, and our findings regarding the applicability for deep water blowout control. Section 9.0 presents potential solutions to the technical hurdles, with conclusions and recommendations summarized in Section 10.

3.0 Deepwater Well Control Barriers

A well barrier is a mechanism to prevent flow from a reservoir to the sea. A well barrier should require no outside force to function other than that required for initial activation.

3.1 Barrier Types

Table 2 (Holand, 1997) describes various barrier types grouped according to their function, their method of operation and how failures are observed.

Barrier Type	Description	Example
Operational Barrier	A barrier that functions while the operation is carried out. A barrier failure will be observed when it occurs.	Drilling mud, wireline stuffing box
Active Barrier (Standby Barriers)	An external action is required to activate the barrier. Barrier failures are normally observed during regular testing.	BOP, Christmas tree, SCSSV
Passive Barrier	A barrier in place that functions continuously without any external action.	Casing, tubing, kill fluid, well packer
Conditional Barrier	A barrier that is either not always in place or not always capable of functioning as a barrier.	Stabbing valve, VR plug, SCSSV

Table 2 - Typical Well Barriers

Two independent barriers are typically used for well control. If the well is in a static condition (i.e., no flow from the reservoir) the primary barrier is usually the hydrostatic pressure exerted by the fluid column (either static or dynamic). The secondary barriers would be the pressure control equipment such as the blow out preventer (BOP), the wellhead (innermost casing hanger seal), and the choke/kill line valves. These barriers are routinely found during drilling, completion and workover operations.

If the well is flowing (i.e. producing oil and/or gas), the primary barrier is that which is closest to the reservoir. This typically includes the packer and associated seal assemblies, the tubing between the packer and the Surface-Controlled Subsurface Safety Valve (SCSSV) and the SCSSV itself. The secondary barriers would then include the tubing above the SCSSV, the master valve of the Christmas tree, the casing and tubing hanger seals and the annulus valves.

3.2 Subsea Drilling Equipment (Deepwater)

Subsea drilling equipment has evolved over the years into complex yet reliable systems. The subsea drilling pressure control system comprises several inter-related components including:

- Wellhead Assembly
- BOP Stack
- Choke & Kill Line System
- Riser System

Current subsea drilling arrangements require that pressures caused by well influxes be contained at the sea floor. Riser systems are not designed to handle the pressures associated with kick removal. These pressures are accommodated by the choke and kill line systems that extend from the subsea BOP stack to the surface, as shown in Figure 3.

3.2.1 Subsea Wellhead Assemblies

The subsea wellhead provides a structural base for the casing strings as well as the other drilling pressure control components. It also provides a receptacle for landing the successively smaller casing strings on hanger assemblies that seal in the wellhead housing to form part of the passive pressure barrier system. Figure 4 illustrates a typical subsea wellhead assembly.

Modern wellhead systems employ complex metal-to-metal sealing technology and mechanisms. These seal systems make-up a primary component in the passive barrier system. A failure of a casing hanger seal would, in the event of pressure, allow that pressure to be imposed on the next outer casing string and associated wellhead seal. Such a situation could cause underground flow from the reservoir to the sediment at the bottom of the outer casing (i.e. the casing "shoe"). This is known as an underground blowout. If the outer casing string or wellhead seal can not withstand the imposed pressure, a blowout could erupt outside the wellbore (i.e. broach).

3.2.2 BOP Stack

Figure 5 shows a typical subsea BOP stack. The individual BOP cavities that make up the BOP stack are connected together with API standard flanges or hub connectors. The BOP stack is modularized within a steel framework that reduces the stresses on these connections. The consequence of a leak from one of these connections depends on its position in the BOP stack and what, if any, pipe is in the BOP stack at the time of failure. The annular (or "Spherical") BOP is designed to seal on any size tubular in the BOP stack. Most annulars can create an effective seal even when there is no pipe in the well. With the exception of the shear blind rams (SBRs), the ram preventers in the BOP stack are designed to seal around either one particular size of pipe or on a certain range of pipe ODs (e.g., 2 7/8" to 5" or 3 ½" to 5", etc.). Thus, if a BOP connection leak were to occur anywhere along the BOP stack while, say, drill collars were in the BOP stack and the variable bore rams (or their control system) were not functioning it would not be possible to isolate the leak with a pipe ram.

3.2.3 BOP Connectors (Lower & Upper)

The BOP stack attaches to the wellhead housing with a hydraulically actuated connector ("Lower Connector" or "Wellhead Connector"). This connector provides a means to disconnect the BOP stack when required. The lower connector constitutes part of the passive barrier system during drilling and workover operations. It must be capable of maintaining a pressure seal equal to the rating of the BOP components under high stresses imparted by the BOP stack and riser. This connector is extremely critical since it is always below the BOP stack, see Figure 6.

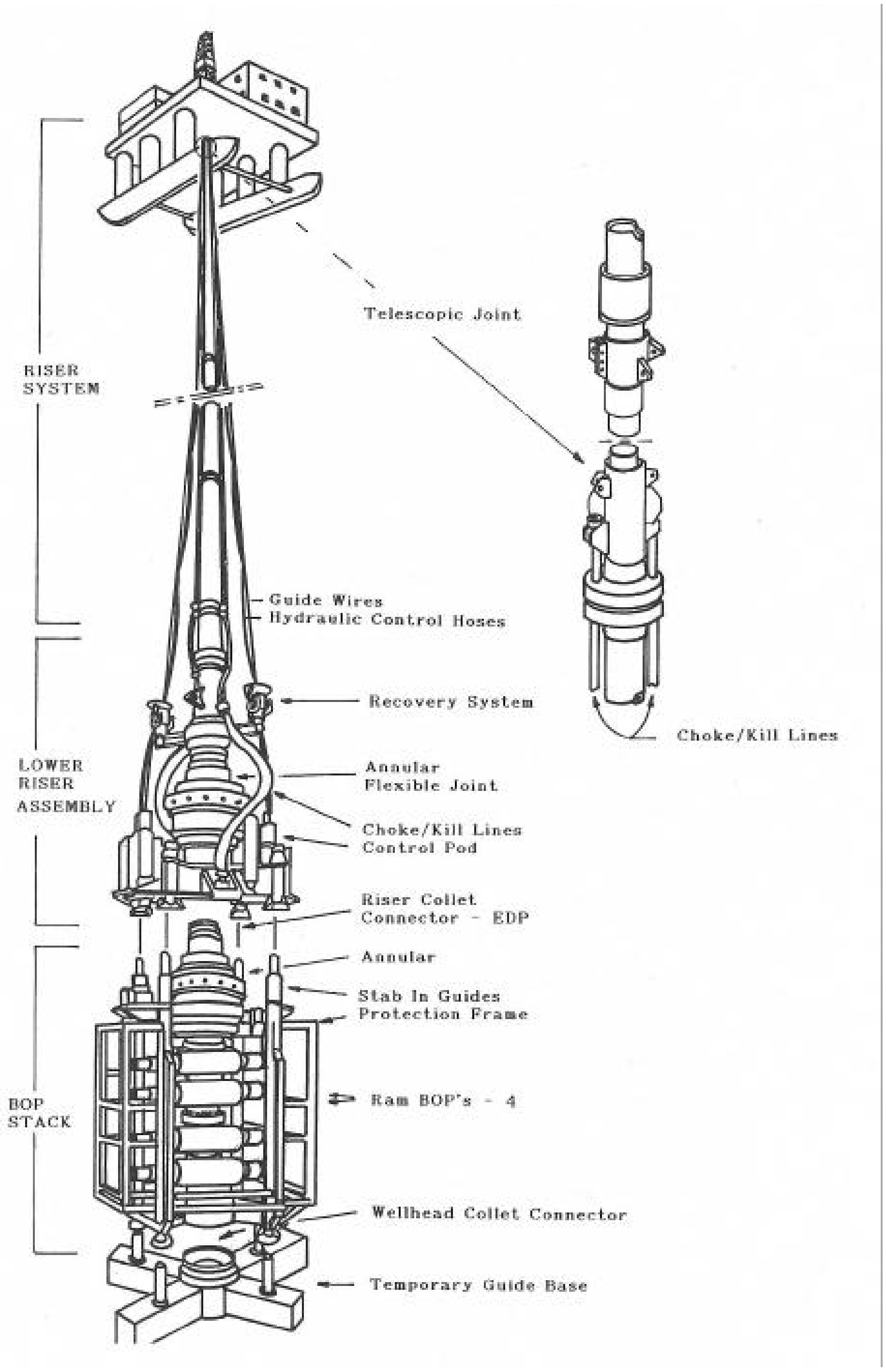


Figure 3 - Typical Deepwater Drilling System (Mather, 1995)

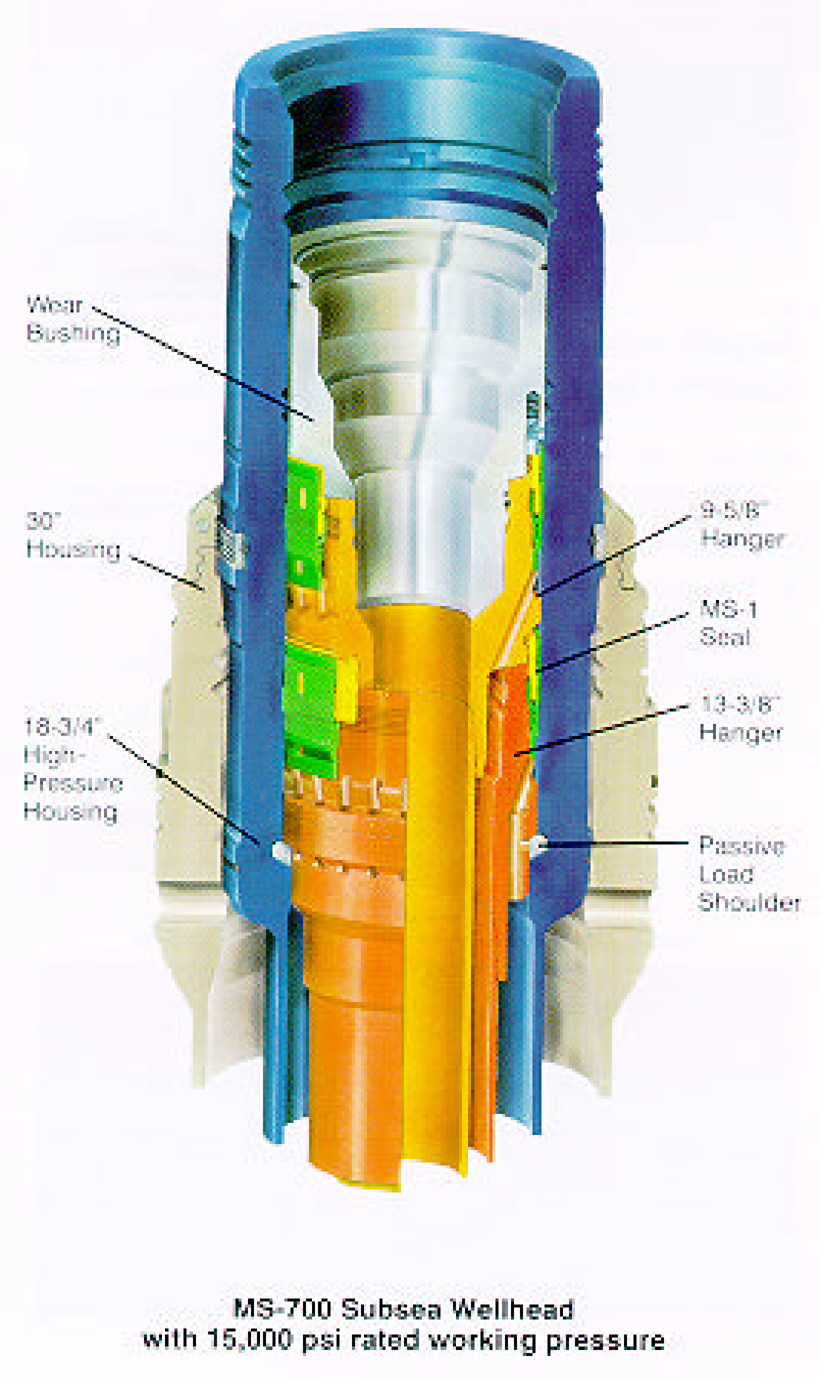


Figure 4 - Subsea Wellhead Assembly

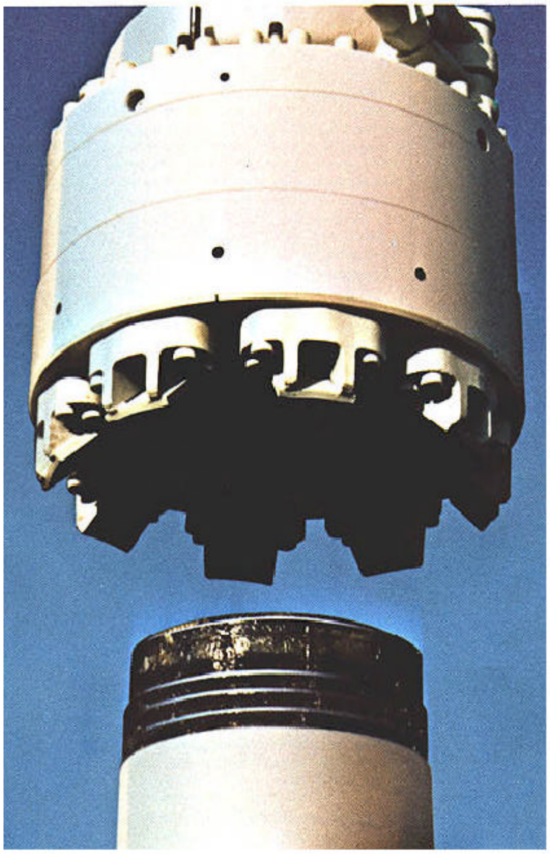


Figure 5 - Subsea 18 ¾” BOP, and Figure 6 - Vetco H-4 Wellhead Connector

The riser system can be detached from the BOP stack via a similar hydraulic connector "Upper Connector" or Lower Marine Riser Package (LMRP) Connector. Typical deepwater BOP systems utilize a 4 or 5 ram/ 2 annular arrangement. One annular BOP (lower annular) is part of the BOP stack while the other (upper annular) is sometimes part of the LMRP, as shown in Figure 3. The LMRP also includes the electro-hydraulic control pods and the flex joint. In an emergency, a floating drilling rig might actuate the emergency disconnect sequence of activities that includes (among a long list of activities):

- Hanging off the drill pipe on rams
- Shearing the drill pipe with specially designed rams (Shear Blind Rams/SBR). These rams also seal the wellbore after shearing the pipe.
- Disconnecting the upper connector and removing the LMRP and riser assembly

3.2.4 Choke and Kill Lines

Other sealing components on the BOP stack include the choke and kill line connectors (or "Stabs") and the choke and kill line valves. The BOP stabs are connected to the telescoping slip joint at 180-degree phasing. In conventional water depths, these 3" lines are usually Coflexip or Goodall type hoses that range from 50 ft. to 75 ft. in length. (Figure 7) The sealing mechanism consists of weight set seal arrangements accompanied by a support pin that is secured to the slip joint. The deepwater BOP systems utilize a “hub” connection to secure the two lines to the slip joint.

Some BOP stacks are arranged so that the kill/choke line is above the lower ram BOP cavity, others are not. API RP 53 (API, 1997) leaves the placement of such lines optional based on “preventer ram placement”. If the choke or kill line placement is below the bottom ram preventer, a leak at this connection would certainly be catastrophic since there would be no means to isolate it with a BOP.

All choke and kill lines used on LMRPs are required by industry standards to meet API 16 C testing requirements for choke and kill applications (API, 1993). The choke/kill lines meeting this specification have had prototypes subjected to testing in an extremely harsh environment with continuous pressure cycling for a period of thirty days. At the end of the testing, the lines are subjected to rapid decompression and inspected for any separation or delamination of materials.

All choke and kill line connectors have dual valve assemblies at the junction where they attach to the BOP stack. At least one of these redundant valves must be a "Fail Safe" or "Fail Close" valve. This means that in the event that hydraulic control is lost, the valve will automatically close. These valves attach to the BOP body via a standard API flange or hub connector. Just like the connection between the BOP bodies, the consequences of a leak from one of these connections is dependent upon its position relative to the rams and what tubing is in the BOP stack at the time of failure.

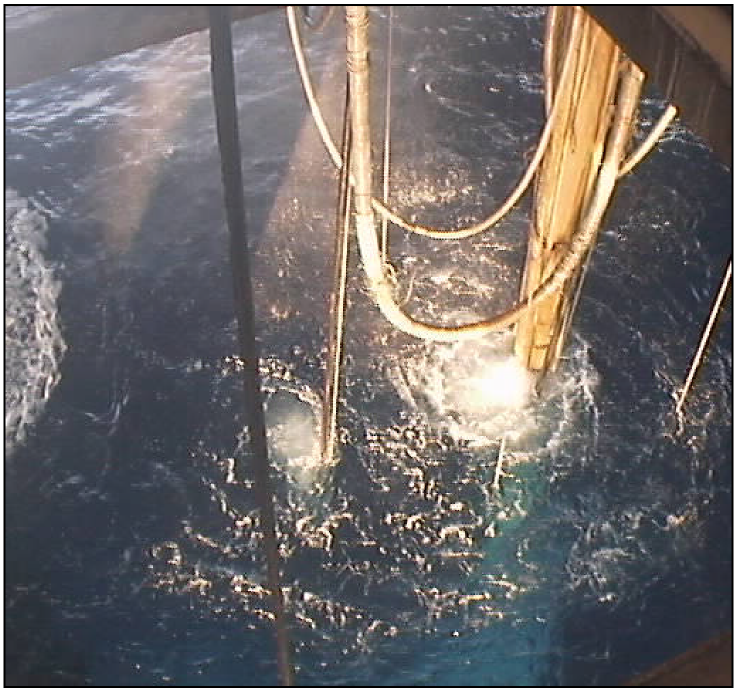
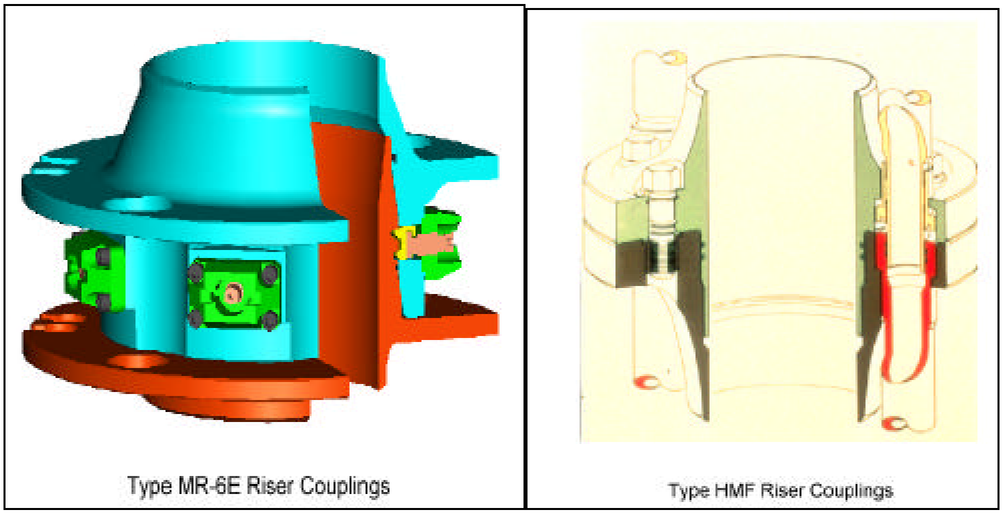


Figure 7 - Choke & Kill Hoses in Moonpool

3.2.5 Riser/Slip Joint

The riser's main function is to be a conduit from the subsea BOPs to the Mobile Offshore Drilling Unit (MODU). This allows drilling fluids and cutting to be circulated through the rig's active mud system. There are two different types of riser couplings that are currently used today. For deepwater operations (Over 3,000 ft.) a flanged connection (HMF Type) is primarily used. (Figure 8.) In conventional water depths, an energized "dog" arrangement (MR-6C/D/E Type), as seen in Figure 8, is used. These designs have excellent integrity and historically the conventional water depth designs have not failed during well control operations.



Type MR-6E Riser Couplings

Type HMF Riser Couplings

Figure 8 – Riser Couplings

The telescoping joint or “slip joint” (Figure 9) is the weakest link in the well control equipment. Case histories have shown where gas in the riser has had catastrophic consequences. If gas is allowed to enter the riser, the diverter system is the only means to keep gas off the rig floor. Most diverter systems are low pressure rated and will not handle pressures greater than 1,500 psi. The packing elements are split or solid and can be operated by air or hydraulic pressure.

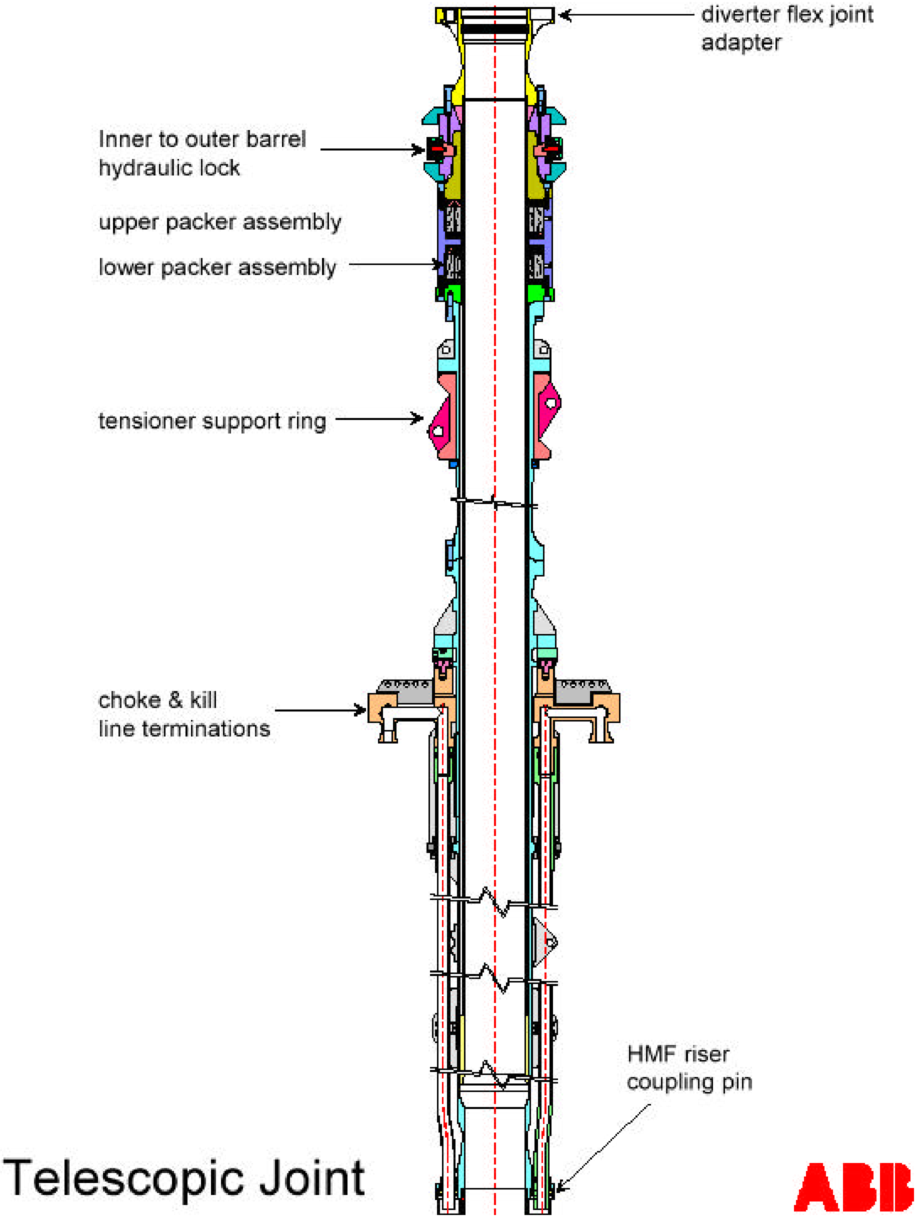


Figure 9 - Slip Joint

3.3 Subsea Completion Equipment

Wells in deepwater are normally produced through subsea production trees ("Christmas Trees"). These can be either a "stand alone" system called a satellite well or they may reside on a subsea template with many other wellheads. Current deepwater production schemes include subsea welltemplates tied into fixed or floating production facilities or tied into a Floating Production, Storage and Offloading Facility (FPSO). In either case, the subsea well template may have several satellite wells connected to it via seafloor pipelines.

A typical scenario is to drill the subsea well(s), complete them (i.e. install packers, tubing, SCSSVs, etc.) and install a production tree that connects to the wellhead housing that was used during the drilling phase. A typical subsea production tree is shown in Figure 10.

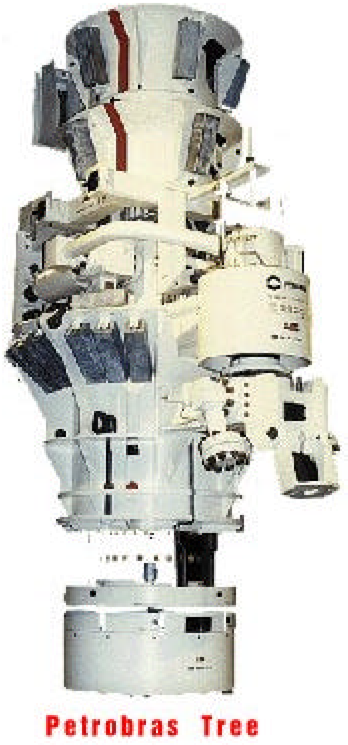


Figure 10 - Typical Subsea Production Tree

The connector where the subsea tree attaches to the wellhead housing is a critical component. A leak from this connection can not be isolated via the tree valves. However, once a well is in production, other passive and active barriers exist for isolation. Examples of these include the tubing, packer and SCSSV.

Subsea trees include connectors where the flow line connects to the tree. These connectors are similar in nature to the choke and kill line connectors on a subsea BOP stack. These connectors are always positioned so that they can be isolated with dual (redundant) valves on the flow side of the tree assembly. They can also be isolated via the SCSSV assuming the tubing below the SCSSV remains intact.

4.0 Blowout Scenarios

The potential leak points on subsea drilling and production equipment are many. One of the major components of safe drilling and production operations in the subsea environment is redundancy. Wherever possible, critical sealing and control mechanisms are backed up by at least one redundant system.

The following deepwater blowout scenarios were developed by Wild Well Control Inc. based on their experience with subsea blowouts. As part of the scenario development, the relative likelihood of a deepwater blowout occurring as described in the scenarios was ranked using the terms “low”, “moderate” and “high”. The relative likelihood assigned to each scenario was based on a critical component analysis as summarized in Section 5. Additionally, the relative consequence of the scenario was ranked using the descriptive terms “minor”, “severe” or “catastrophic”.

4.1 Drilling, Completion & Workover Blowout Scenarios

Possible scenarios for sustained blowouts during the drilling, completion and workover phases include:

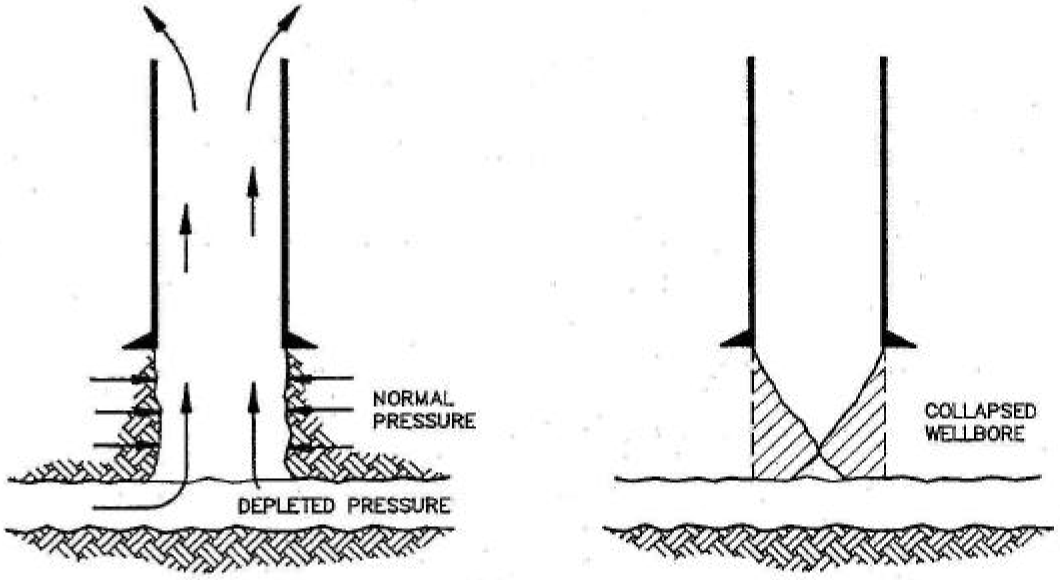
- through the riser, drill pipe/tubing, choke/kill lines at the rig
- through leak paths on the BOP/wellhead at the seafloor
- at the seafloor that are outside the wellbore (Broached)

These scenarios are not water depth dependent.

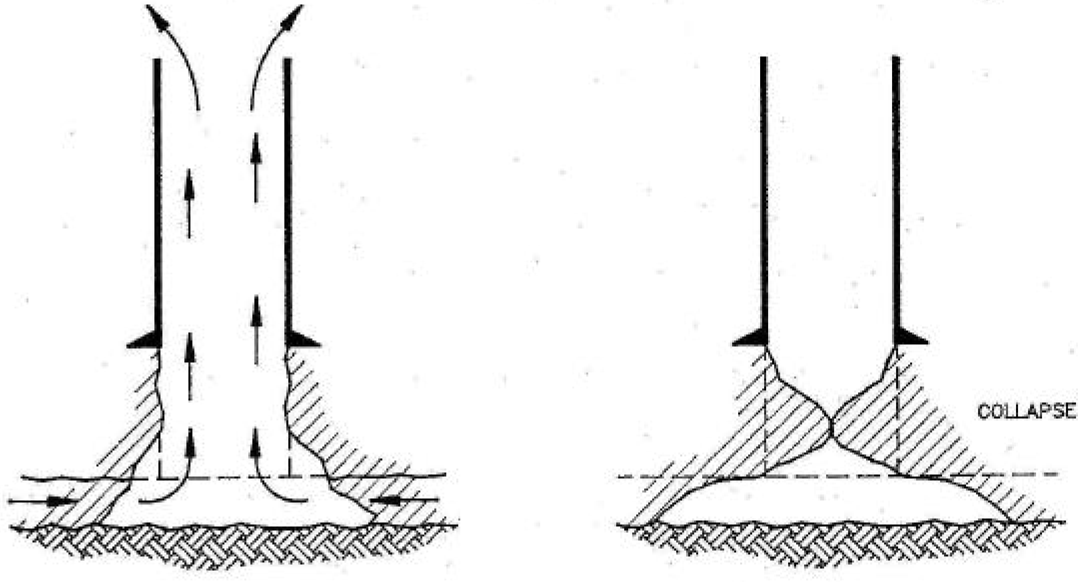
The major difference between a blowout during the drilling phase versus the completion or workover phases is the drilling well tendency to "bridge off". Bridging is a phenomenon that occurs when severe pressure differentials are imposed at the well/reservoir interface, and the formation around the wellbore collapses and seals the flow path. See Figure 11. Such pressure differentials occur when a well is allowed to flow freely such as might be the case during a sustained blowout. Deepwater reservoirs are notoriously susceptible to collapse under "high draw down" conditions. Completion schemes often include methods to stabilize the reservoir during production in order to reduce the production of solids in the flow stream. The most popular method is called a gravel pack completion. Thus, a completed well may not have the same tendency to passively bridge off as would a drilling well involving an open hole (uncased) interval. The tendency to passively bridge may also be inhibited by the seawater column back pressure which may limit the flow rate and prevent collapse of the well. In these cases, active bridging methods may be considered to close the hole. Bridging may have a beneficial effect for spill control by slowing or stopping the flow of oil from the well.

There is a difference of opinion between blowout specialists on the likelihood of deep water wells bridging off naturally in a fairly short time. There are a number of well characteristics that must be evaluated in order to accurately predict the probability of a particular deep water well bridging off, including:

- Reservoir Data



PRESSURE DRAWN DOWN IN THE BLOWING ZONE
ALLOWS EXPOSED NORMAL ENVIRONMENTS TO COLLAPSE



EROSION ALLOWS WELLBORE DESTABILIZING AND BRIDGING

Figure 11

Wellbore Bridging

(Neal Adams Firefighters, Inc., 1991)

DEA PROJECT NO. 63

JOINT INDUSTRY PROGRAM
for
FLOATING VESSEL BLOWOUT CONTROL

- Well Design
- Casing Design
- Seismic Data
- Open Hold Data (length, size, etc.)
- Blowout Effluent
- Blowout Rate

A blowout could occur through the riser, choke or kill line or the drill pipe during the drilling phase (or tubing during the completion/workover phase). The first line of defense during these phases is the hydrostatic pressure created by the mud column. This barrier can be compromised by well influxes or losses of circulation. Suitable back up barriers exist for these situations including the BOPs, casing and wellhead assembly. Figure 12 shows an example of a blowout through a choke line hose.

Figure 12 - Blowout and Fire from Failed Choke Line

Example Blowout Scenario #1 (Through Riser)

Likelihood Rank: Moderate
Consequence Rank: Severe

While tripping out of the hole with the drilling assembly (drill pipe, drill collars, etc.) an unexpected increase in the volume of mud returning to the mud tanks (influx) is observed while the 6 ½" OD drill collars are across the BOP stack. The lower annular is closed. Surface pressure increases beyond the pressure rating of the annular BOP (typically 5,000-psi). The Variable Bore Rams (VBRs) are actuated but will not operate. The shear blind

rams (SBRs) are actuated but fail to shear the drill collars (SBRs will not usually shear drill collars) and seal the wellbore. The annular BOP suffers a sudden, catastrophic failure and the well flow is released up the riser. The flow destroys the diverter line at the surface and the telescoping joint on top of the riser is thrust through the drill floor.

Commentary: This is a possible scenario as the ability to implement the "method of last resort" (i.e. shear the pipe and disconnect) is not an option when items such as drill collars are in the BOP stack. Most influxes do not result in surface pressures beyond the rating of the annular BOP. However, some do by virtue of their intensity or being mishandled. It is not uncommon to find that gas influxes are not handled correctly when the pipe string is shallow. Correct handling in these situations requires the implementation of volumetric well control procedures that are not always well understood by field personnel. Refer to the IADC deepwater Well Control Guidelines (IADC, 1998) for well control procedures.

The riser would most likely collapse once the oil and gas started flowing through it. This is caused by high differential collapse pressures when the riser becomes filled with low-density fluids and is crushed by the high seawater pressures. Once the rig was shut down, all power would be shut off and the air pressure would eventually bleed off from the riser tensioners and the drill string compensator. This would exert additional forces on the riser and wellhead assemblies. The riser dump valve should be opened in the event of possible gas in the riser. This will give the expanding bubble an exit point if a small diverter system is on the rig (10"). This will also help keep the hammer effect off of any bends in the diverter system. (Figure 13.)

Figure 13- Riser Dump Valve

This well would probably bridge off unless the exposed reservoir was extremely well consolidated and the other sediments in the open hole section were very stable.

Blowout Scenario #2 (Through Drill Pipe/Tubing)

Likelihood Rank: Low
Consequence Rank: Catastrophic

During completion operations, the rig crew was pulling out of the hole after setting the gravel pack completion when an influx was observed. The well was shut in with the annular BOP and conventional circulation techniques were initiated to remove the influx. During the circulation, a hole developed in the tubing string at a connection (washout). High annular pressures caused by the influx near the seafloor (i.e., just below the BOP stack) communicated to the inside of the tubing string. The safety valve on top of the tubing began to leak where it was connected to the tubing string. Attempts were made to activate the SBRs but they did not shear the pipe for unknown reasons. While the crew was making repeated attempts to actuate the SBRs, the leak at the top of the tubing string (i.e., at the rig floor) increased dramatically as the mud was pushed out of the tubing and eroded the leak path. The rig was shut down and abandoned.

Commentary: This is a possible scenario but would require the complete failure of the SBRs. As stated in earlier sections, all control systems include a back up system. In this case, the redundancy is found in the dual multiplex control systems that include completely independent control pods and surface actuation systems. Any scenario that involved sustained flow through the choke and/or kill lines would also have to involve the failure of the multiplex control systems. It should be noted that additional back up systems are available. These include acoustically actuated controls and ROV intervention.

This scenario would not lend itself to bridging since the gravel pack completion is already in-place and the wellbore is cased. Figure 14 shows a drill pipe blowout.

Blowout Scenario #3 (Leak On Wellhead Connector)

Likelihood Rank: Moderate
Consequence Rank: Catastrophic

While circulating an influx from the wellbore via conventional circulation techniques (bit near bottom, drill pipe hung off on middle pipe rams), a visual observation with the subsea camera indicates activity beneath the BOPs. Circulation is suspended while pressures are observed. During this time, bubbles are observed on the port (down current direction) of the rig. The ROV is launched. Observations by the ROV and subsea camera conclude that the wellhead hydraulic connector is leaking and the BOP stack is leaning approximately 3^{O}. Circulation is resumed in an attempt to clear the influx from the wellbore while the ROV remains near the seafloor to observe the leaking wellhead connector. After a short time the leak is reported to be increasing steadily. The ROV is retrieved and the emergency disconnect sequence is activated. The drill pipe is sheared, the LMRP is disconnected and the rig is moved off station.

Figure 14– Drill Pipe Blowout

Commentary: This is also a reasonable scenario, as it is impossible to isolate the wellhead connector with any of the rams. It should be noted that wellhead connectors (Figure 6) have an extremely good record of dependability. However, as deepwater activity increases so do the probabilities of such a failure. In addition, increased water depths create higher bending moments on the subsea equipment, which, in turn, may increase the odds of a connector failure**.** If a control system failure were to occur, the wellhead connector may become unlatched, and the wellbore pressure may exit from below the connector or the seal ports. (Figure 15)

Even though this scenario involves a drilling well with an open hole section, the probability of bridging is reduced since the leak is through a relatively small opening. This would reduce the pressure differential at the reservoir and cause a corresponding decrease in the volume of the flow. Erosion ,however, might cause the flow path to enlarge over time.

This scenario could be related to any leak on the BOP stack that could not be isolated with one of the rams. This would include choke or kill lines below the lowermost BOP, leaks with drill

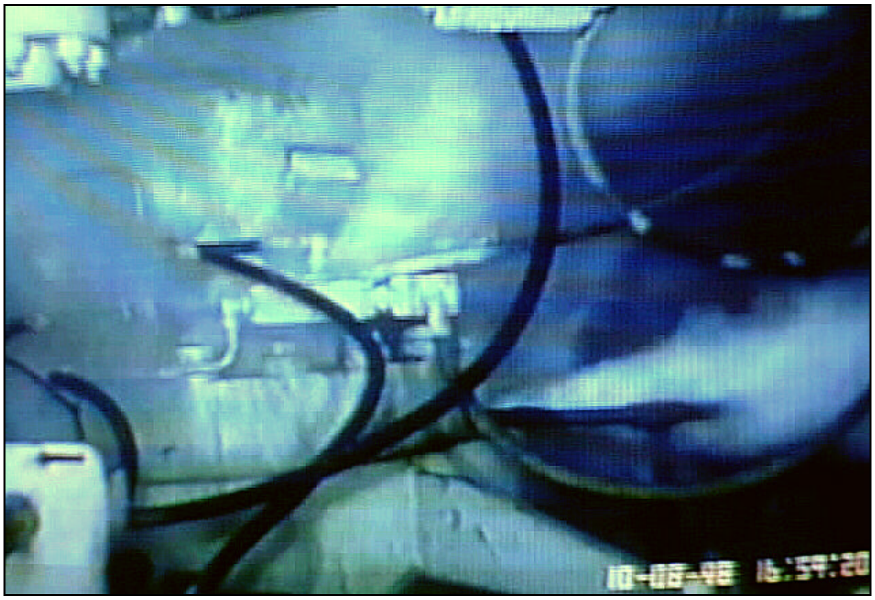


Figure 15- Seal Port Failure

collars or irregularly shaped tools in the BOP stack or leaks on the BOP stack below the SBRs with no pipe in the hole. Water depth would not have a bearing on the probability of choke and kill line connection leaks as the imposed loads on the choke and kill line connections are not dependent on water depth.

A similar scenario could develop wherein a completed well was involved during completion or workover activities. All factors would be the same with the exception of the well's propensity to bridge off if the flow path were to be enlarged via erosion.

Blowout Scenario #4 (Broach)

Likelihood Rank: Moderate
Consequence Rank: Catastrophic

While drilling below the 9 5/8" casing an influx (kick) occurs. Conventional circulation techniques are initiated to remove the influx. During kick removal a complete loss of circulation is observed, and visibility is reduced below the subsea BOPs. Soon, bubbles are observed some distance from the rig. The ROV is deployed but becomes entrained in the blowout plume during descent. The ROV becomes entangled on the riser and is rendered useless. The surface bubble activity steadily increases and the rig is forced to shear the pipe, disconnect the LMRP and move off station.

Upon further investigation a second ROV reports that the flow is exiting the seafloor 20-m from the wellhead. Figure 16 shows the surface boil from such a broach scenario.

Figure 16 - Surface Boil Due to Well Broaching

Commentary: The pressure required to initiate a fracture of the subsurface sediment (usually expressed in psi/ft) is a major factor in the design of casing for any well. Pore pressure (the pressure of the formation fluids) generally increases with depth, which requires higher mud densities. At some depth the required mud density approaches the fracture pressure at the last casing shoe. Thus, another casing string is required in order to continue drilling. The depth of the subsequent casing string is determined based on anticipated pore pressure with consideration given to the possibility of an influx. The last casing shoe must be capable of withstanding the mud weight used for drilling as well as the pressures developed during kick circulation. The difference between the mud weight and the pressure exerted by the mud column in addition to anticipated surface pressures is called the "kick margin". If the kick margin is not adequate, an underground blowout is likely if a severe influx is encountered.

If the innermost casing string fails to contain the pressure associated with an influx (channeled cement, hole in the casing, leaking wellhead seal, etc.), the pressure will be communicated to the next casing string which almost certainly will not be designed to handle such pressures either because of its burst rating or the fracture strength at the casing shoe. Naturally, as the point where the flow is exiting the wellbore becomes shallower, the probabilities increase that it will create a flow path to the seafloor.

Deepwater drilling requires the placement of additional casing strings at shorter intervals than shallow water or land drilling due to the lower fracture gradient of the sediments. Thus, it is not uncommon to have small kick margins during deepwater drilling. See Section 1.3 of the IADC Deepwater Well Control Guidelines (IADC, 1998) for a comprehensive discussion of drilling fluid management considerations.

4.2 Producing Well Blowout Scenarios

Completed wells (i.e., those in production) present more severe consequences in the event of a blowout due to the hole being fully cased down to the producing formation, lowering the probability of bridging. However, producing wells have numerous active and passive barriers in place in addition to the normal redundancies found in all deepwater systems.

Subsea production trees attach to the wellhead housing connector in a fashion similar to the BOP connector used during drilling. These trees often include redundant valves inline with the flow stream. These trees are fabricated in a single forged block to reduce the number of flange or hub connections.

Subsea trees are monitored and controlled via electro-hydraulic and/or multiplex control systems. Pressure and temperature sensors continuously monitor the tree and the system is programmed to actuate active barriers at pre-set values. *Any sustained blowout on a subsea production well will have to involve failures of multiple active and/or passive barriers.*

Blowout Scenario #5 (Tubing Failure Below SCSSV)

Likelihood Rank: Low
Consequence Rank: Catastrophic

A satellite production well tied-back to a tension leg platform was automatically shut-in (SCSSV, master & wing valves closed) by the subsea control system due to high annular pressure. Shortly thereafter, a surface disturbance was reported by a standby vessel near the wellhead location. ROV inspection concluded that there was a flow exiting the wellhead housing connector. The operator made arrangements to inject kill fluid into the subsurface tree via the flow line. However, erosion created a flow path that caused all kill fluids to be ejected at the wellhead.

Commentary: This situation could only develop if the tubing lost pressure integrity below the SCSSV and the tubing hanger seals failed and the wellhead connector failed.

Blowout Scenario #6 (Flow Line Damage)

Likelihood Rank: Low
Consequence Rank: Catastrophic

A semi-submersible drilling rig was forced to make an emergency disconnect in heavy seas while drilling an offset satellite well near a FPSO facility. An anchor was unset during the disconnect and pulled across a flowline from a nearby subsea well. The flowline was broken off at the connector causing an uncontrolled flow of oil and gas.

Commentary: This scenario would also have to involve multiple failures of redundant control systems. If a flowline were to be broken, the well would be shut-in (due to the sudden flowing pressure decrease) by the master valve, SCSSV and wing valves. Thus, this scenario is very unlikely. This scenario would not likely occur in water depths roughly greater than 4,500 ft since drilling vessels in greater water depths are typically dynamically positioned.

Some flowlines are miles in length. The isolation valve may be located a great distance from the leak path. It may take quite some time to respond and physically close the isolation valve, which will continue to spill product into the ocean. Even after the valve has been closed, it will take time to bleed down and clear the line.

5.0 Critical Component Analysis

The following table (Table 3) is a matrix, developed by Wild Well Control, indicating the ranking of potential exit points according to the probability of occurrence. This ranking does not indicate the likelihood of a sustained blowout being caused by a leak at or through any of the potential leak points. Such probability is included in the consequence ranking which follows (see Section 6.0).

These summary tables give an indication of components which are likely sources of flow, and source control, which should be addressed in well specific blowout contingency plans.

5.1 Drilling, Completion & Workover Operations

Possible failure points during drilling, completion and workover operations have been summarized in Table 3. Based on their experience with the very few problems that have been associated with these components (which were described in Section 3.2) Wild Well Control Inc. developed the blowout scenarios contained in Section 4, which assigned a probability associated with the likelihood of a deepwater blowout occurring as a result of component failure. The assignment of a probability was subjective, and based on Wild Well's experience and judgement. They have assigned a moderate probability of a deepwater blowout to problems associated with the wellhead connector, LMRP, well flow through the riser, or a broach. There is a lower probability of a deepwater blowout to problems associated with leak paths on the BOP, through the drill pipe/tubing or the casing hanger seals.

	Blowout Probability		
	Low	**Moderate**	**High**
Wellhead Connector		**X**	
BOP Flange/Hub Connection	**X**		
Choke/Kill Connection to BOP	**X**		
Choke/Kill Stab (LMRP)		**X**	
Through Riser		**X**	
Through Drill Pipe	**X**		
Broach		**X**	
Casing Hanger Seals	**X**		

Table 3 - Ranking of Potential Leak Points (Drilling/Completion/Workover)

5.2 Producing Wells

A similar table was developed for producing wells based on Wild Well Control's experience. See Table 4. They have assigned a moderate probability of a deepwater blowout to problems associated with the annulus valve, while all other components were assigned a low probability.

	Blowout Probability		
	Low	**Moderate**	**High**
Wellhead Connector	**X**		
Flowline Connector	**X**		
Annulus Valve		**X**	
Broach	**X**		
Casing Hanger Seals	**X**		

Table 4 - Ranking of Potential Leak Points (Producing Wells)

6.0 Consequence Analysis

The consequence analysis attempts to rank the consequences of a leak at various potential leak points. The consequence is primarily related to the ability to isolate the leak point via active barriers. This establishes the likelihood that a sustained blowout will result from a leak at any given point.

6.1 Drilling, Completion & Workover Operations

Table 5 assigns a consequence ranking to indicate the likelihood of a sustained blowout being caused by a leak at or through the potential leak points from Table 3. These relative rankings were developed by Wild Well Control Inc. based on their experience with the very few problems that have been associated with these components. They have assigned a "catastrophic" rating to a release through the drill pipe or from a broach, because the drill rig would likely shut down and be abandoned, or move off location, if these were to occur (see the blowout scenarios in Section 4). A similar result could occur as a result of blowouts originating at the wellhead connector or through the riser. These were assigned a "severe" ranking by Wild Well Control, while those associated with the BOP and LMRP were assigned a "minor" ranking.

	Relative Consequence		
	Minor	**Severe**	**Catastrophic**
Wellhead Connector		**X**	
BOP Flange/Hub Connection	**X**		
Choke/Kill Connection to BOP	**X**		
Choke/Kill Stab (LMRP)	**X**		
Through Riser		**X**	
Through Drill Pipe			**X**
Broach			**X**
Casing Hanger Seals		**X**	

Table 5 - Ranking of Consequences Due to Leaks at Various Points (Drilling/Completion/Workover)

6.2 Producing Wells

A similar table was developed for producing wells based on Wild Well Control's experience. See Table 6. They have assigned a "catastrophic" consequence of a deepwater blowout to a broach, and "severe" to blowouts resulting from the wellhead connector or casing hanger seals, while all other components were assigned a low probability. These relative consequence rankings are consistent with those applied to those for drilling, completion and workover operations.

	Relative Consequence		
	Minor	**Severe**	**Catastrophic**
Wellhead Connector		**X**	
Flowline Connector	**X**		
Annulus Valve	**X**		
Broach			**X**
Casing Hanger Seals		**X**	

Table 6 - Ranking of Consequences Due to Leaks at Various Points (Producing Wells)

7.0 Technical Hurdles to Deepwater Oil Spill Response

The following sections describe probable technical hurdles to be overcome in order to locate, contain, track and recover the uncontrolled flow of oil from the previously identified deepwater blowout scenarios. Problems associated with identifying and correcting the cause of the blowout using well control techniques are discussed in the IADC Deepwater Well Control Guidelines (International Association of Drilling Contractors, 1998) and are not addressed here. Section 7.1 identifies problems associated with subsea containment of oil from a deepwater blowout. Section 7.2 describes technical hurdles foreseen in the subsea injection of dispersants at the wellhead. Section 7.3 defines the problems related to released oil remote sensing and tracking. Section 7.4 identifies problems related to recovery of the oil if it reaches the sea surface. The problems identified in 7.1 through 7.4 are summarized in 7.5.

7.1 Subsea Oil Containment

7.1.1 Deepwater Currents

Deep water currents and the water depth itself will be a challenge for subsea oil containment. The availability of installation vessels with a suitable dynamic positioning system will be a limiting factor. In addition, the lack of information on plume formation and behavior will make it difficult to predict areas where the oil might surface. Predicting the behavior of deepwater currents is a technical hurdle to be overcome for both relief well planning and for modeling plume behavior.

7.1.2 Manipulation of Heavy Objects

Intervention or containment at the wellhead may require the placement and/or removal of large equipment pieces weighing several tons at depth. Manipulation of heavy objects on the seabed by means of a ROV can only be done in conjunction with surface support or subsea lifting devices such as syntactic foam buoys, etc. The blowout area may be filled with debris from the surrounding structure and pipes that have fallen down. In order to access the BOP one may have to remove some of the debris, which could be very difficult to do. Existing technology for ROVs includes hydraulic cutting devices in many different forms suitable for cutting nearly any steel or concrete structure. In order to accomplish this, the ROV will need to move very close to the object and must physically lock itself to it in order to complete the task. The blowout plume and subsea current could make this a very risky and difficult task.

7.1.3 Subsea Collectors

While the logical approach to controlling oil released from a deepwater blowout would appear to be to contain and collect the oil at the blowout source, the difficulties associated with the design and installation of an effective collector in deep water makes these devices impractical.

The Ixtoc 1 collector, Figure 17, despite being suspended from a jackup platform in rather shallow water, suffered damage during a storm and was given up and dismantled before the

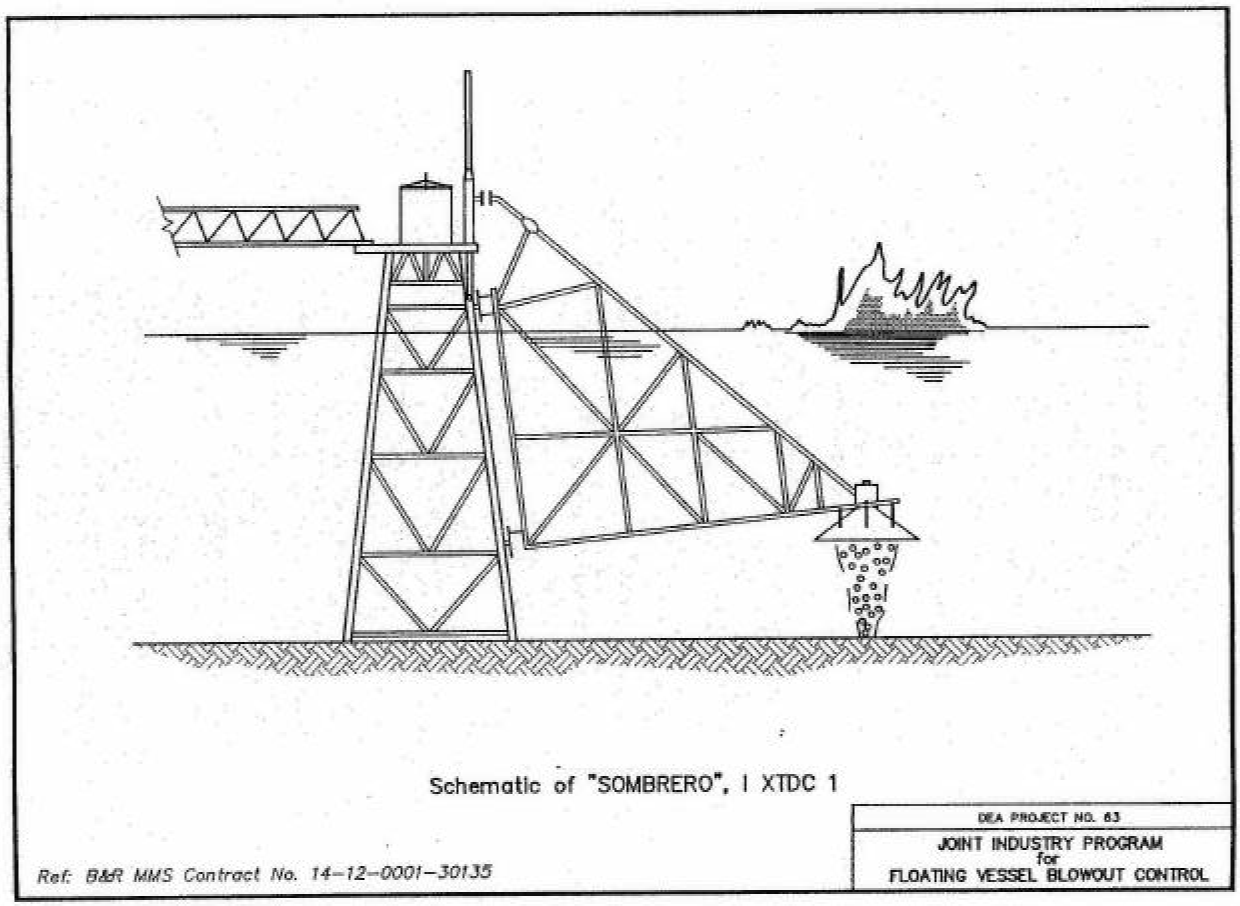


Figure 17 – The IXTOC 1 "Sombrero" Collector

blowout stopped. When in operation, it only collected about 15% of the total flow. The balance of the oil passed under the edge of the device because the gas lift riser was unable to transport the enormous amount of water accompanying the oil (Westergaard, 1987). The 1,500,000 bbl/day of effluent recovered by the system contained only 2% oil by volume. Surface separation facilities were overloaded and one-half of the oil collected by this system was discharged over the side with the seawater (Neal Adams Firefighting, Inc, 1991).

After the Ixtoc 1 blowout, MMS blowout research and development concentrated on ship-mounted, deepwater suspended open collector systems (i.e. "sombrero" type) which are bell-shaped, rigid-walled, and provide limited access to the wellhead (Brown & Root, 1985). The research indicated that a bell or cone shaped device could function if properly dimensioned and if it covers the blowout source. The bottom radius of the collector should preferably be one and a half times the anticipated offset error during installation. It should be tall enough to accommodate a 30' tall wellhead assembly. The double collector/double riser shown in Figure 18 was found to be the most efficient, although the exact shape is immaterial. Ability to vent gas will be an important capability for any cap type device. No research on this system has been performed since the 1985 report, which did not address deep water blowouts. The equipment will have to be designed to accommodate a high percentage of water for each ton of recovered oil.

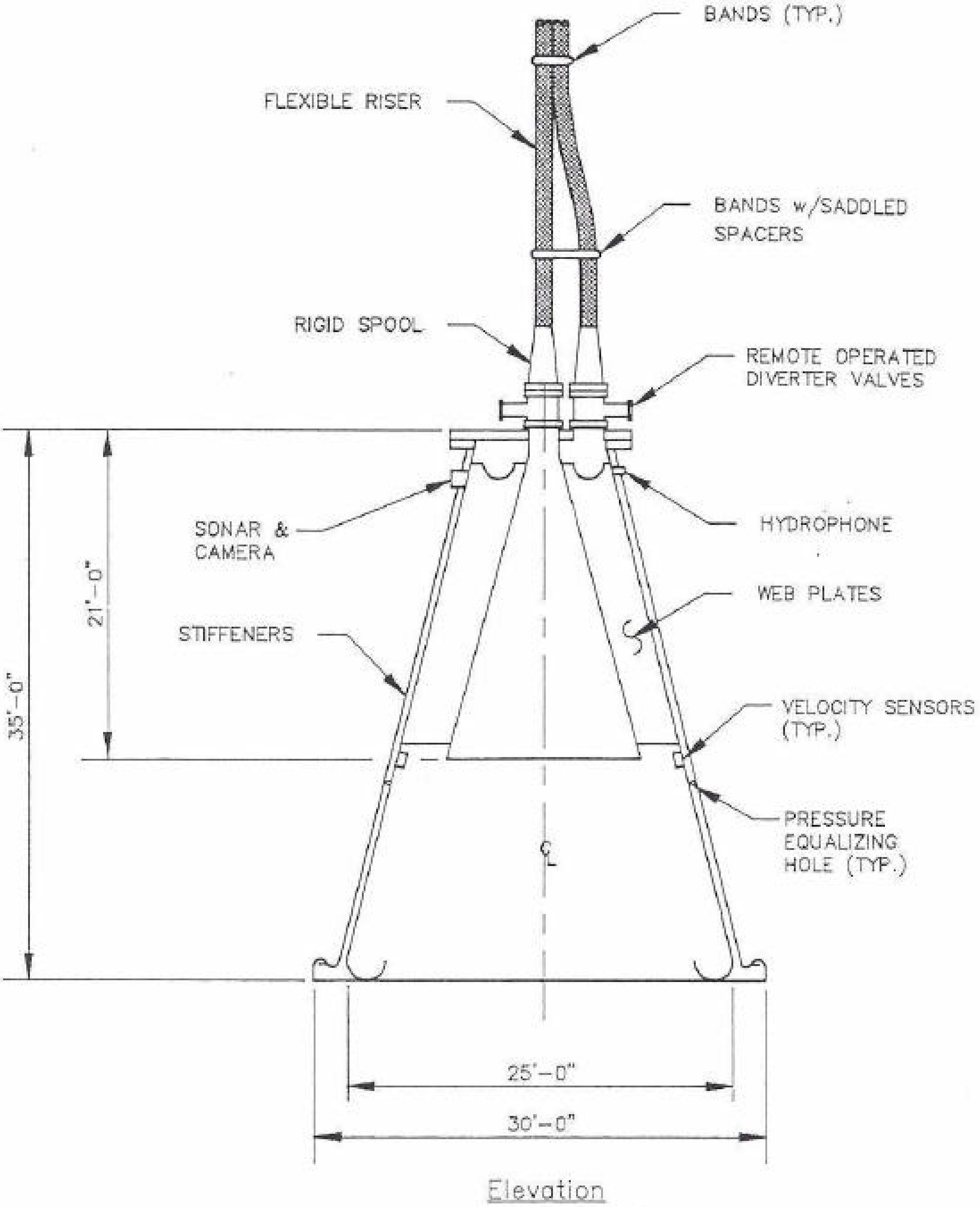


Figure 18

Subsurface Cone*

DEA PROJECT NO. 63

JOINT INDUSTRY PROGRAM
for
FLOATING VESSEL BLOWOUT CONTROL

*After MMS Contract 14-12-0001-30135

The dimensions of the device required to accommodate this volume, in combination with the water depth handling requirements, makes the approach impractical and expensive given the low probability of blowout occurrence. The most serious limitation of the system is the cost, which was estimated at $58,784,000 in 1985.

The latest comprehensive summary of subsea blowout collection devices is contained in Section 6 of the DEA-63 Project Report (Neal Adams Firefighting, Inc, 1991). This report generally categorizes the collectors as bell-shaped devices, rigid-wall cylinders or flexible columns (See Figure 19). Among the technical hurdles associated with deepwater subsea collectors, the following were included:

- They all limit access to the wellhead to some degree, and most prevent using other types of well control measures such as vertical intervention.
- They have limited tolerance for debris on the seabed.
- None are in stock and few, if any will handle all blowout situations. Long lead times for construction are anticipated.
- They would require a seal against the seafloor to prevent entraining a large volume of seawater in the plume. This situation may be mitigated if a subsea template can be installed around the wellhead or BOP, to which the device can be attached.
- They would require a diameter sufficient to encapsulate the entire stack, with provision to accommodate a leaning wellhead/stack assembly.
- Riser size is critical for bell systems. Small riser diameters result in a backpressure and spill under of oil at the bottom of the bell.
- Rigid cylinders may be limited in deepwater because of the large surface area of the cylinder exposed to current forces along the water column. Heavy anchoring would be required.
- Flexible columns have been shown in laboratory experiments to suffer considerable whipping and flapping associated with the flow of blowout fluids and gas. They lack the ability to withstand significant pressure differentials across the walls.

These difficulties have caused most researchers to conclude that sealed containment of blowout oil is not practical in deepwater with existing technology.

This conclusion was also reached in a recent evaluation of the state-of-the-knowledge and practical opportunities for dealing with submerged oils that was recently published (Brown, et. al., 1998). The authors concluded that in most circumstances, it is not realistic to expect responders to contain or recover submerged oils.

7.1.4 Installation and Approach

The installation of any oil containment device will need to be coordinated with well control personnel. The blowout plume will make it difficult to approach the well with anything but very massive equipment pieces or ROVs. The operation of ROVs will be difficult around the blow out point. The jet zone will cause vast amounts of water to flow towards the well. The danger of having lighter equipment sucked into the flow is large. Many ROVs have been rendered useless by relatively minor blowout plumes. A further complication is that conventional acoustic based navigation systems or sensors on the ROV may not work as intended due to the heavy turbulence in the area. Both Acoustic Doppler Current Profilers (ACDPs) and ROV mounted tracking

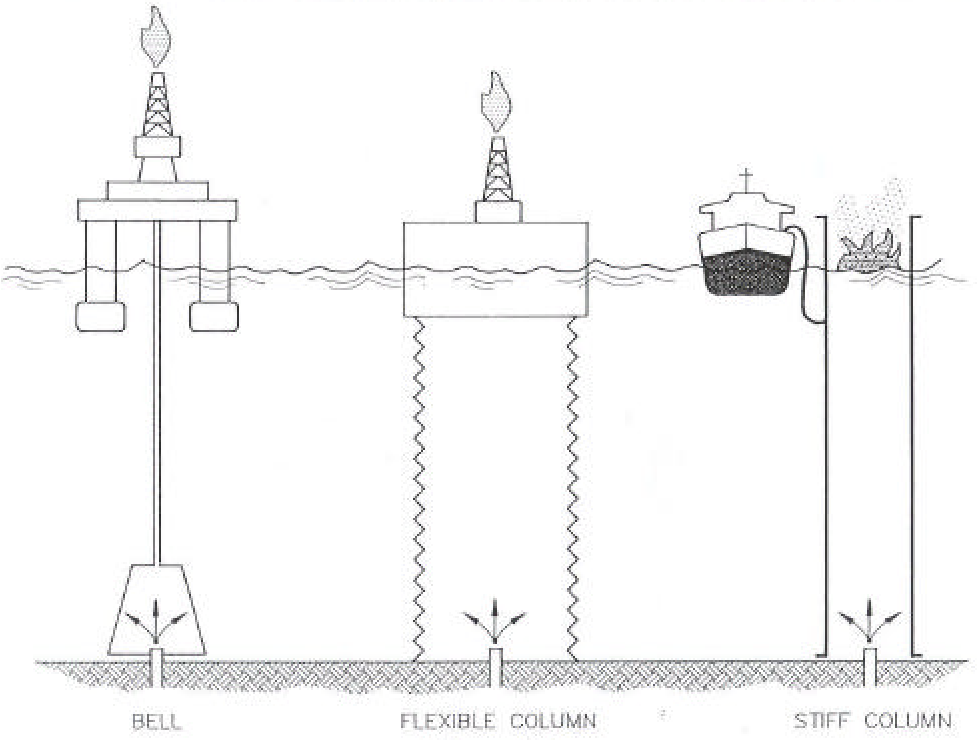


Figure 19

Schematic of Bell Shaped, Rigid Wall and Flexible Sided Columns

acoustic systems may have problems due to diverted acoustic signals from the blowout plume gas. Air bubbles from the gas released in the 1996 Norwegian field trials simulating a blowout event (Rye and Brandvik, 1997) reportedly distorted the signals necessary for the underwater positioning system on both the ROV and research vessel (Brandvik, 1998). Alternate ROV control methods will require development. Wells contained on subsea templates may not be accessible with ROVs. Cratering of the sea floor around the well may also worsen the situation. A large crater will make access to the point of the outflow very difficult. Water will be pulled into the stream along the seabed, at the same time sand and particles will be sucked into the stream from the surrounding crater.

The seafloor conditions in deepwater will probably be very unconsolidated. This may make mooring of any containment device to the seafloor difficult and could affect the placement of heavy objects on the seafloor.

7.1.5 Lack of Standardization

Subsea well head and BOP design and operation are not standardized. Containment device sizes would necessarily have to be flexible to fit a large variety of subsea well and satellite designs. Wellhead control options may be limited by the lack of standard manual overrides on subsea gate valve stems or provision of wet stabs which might be used to exit flow or introduce kill fluids.

7.2 Subsea Dispersant Injection

One of the more promising solutions for dealing with a deep water out-flow of oil is to mix the oil with dispersant at the source. Experiments (Westergaard, 1987) indicate that this way of dealing with the problem could be a practical and cost effective method. Only 1% by volume dispersant might be sufficient in order to treat the oil due to the good mixing which will be a result from the violent and turbulent fluid stream. Technical devices and methods to inject the dispersants are not available and a number of technical hurdles can be foreseen. The major hurdle is the method and apparatus for delivering the dispersion to the plume.

7.3 Oil Remote Sensing and Tracking

7.3.1 Understanding of Plume Dynamics

The deepwater currents cited as a technical hurdle for subsea containment will also affect the ability to track the oil after it exits the well. The effects of currents, fluid type, and temperature must be taken into account. Plume theory modeling will be one of the important factors in the ability to trace and project the oil trajectory after a blow out. If plume deterioration occurs, tracking of the oil will be a major hurdle. Reliable proven plume modeling and underwater tracking methods are not available and further research in these fields is needed.

7.3.2 Oil Properties.

The properties of the oil escaping the well will have a significant impact on the ability to track it. The oil properties will effect emulsification, dispersion and possibly whether the oil will rise to the surface or stay submerged. The oil properties will change over time as the plume rises to the surface. Stable emulsions may be formed. Natural subsurface dispersion is expected to be significant with the shearing effects of multi-layered subsurface currents. Oil reaching the surface will be subject to evaporation and other weathering processes. Unless a weathering study of the oil properties is performed on a sample soon after the oil is found during exploration drilling, these properties may not be known at the time of the blowout.

7.3.3 Detection

Although there are a number of techniques, which might be used for detection of submerged oil, none have proven very effective (Brown, et. al., 1998). Fluorometers have been used to detect submerged oil plumes; but large flat, thin layers or “blobs” of oil would not be detected by this method as they operate over a limited concentration range and detect only oil as it passes through the sampling tube. There is only one reported instance of acoustic techniques having been used for detecting and tracking submerged oil. SINTEF (The Foundation for Scientific and Industrial Research in Norway) used an ROV equipped with a sonar operating in the 450 - 650 kHz range during their underwater releases of oil in 1995 and 1996 (Brandvik, 1998). The sonar was commercial equipment made for fish finding. Images from the sonar, and a low light camera, were used to quantify the diameter and position of the plume relative to the release point and the surfacing position. They succeeded in measuring the diameter of the plume vs. depth, but had problems fixing the position of the plume since the exact location of the ROV could not be determined. Air bubbles from the gas released in the 1996 field trial simulating a blowout event

(Rye and Brandvik, 1997) reportedly distorted the signals necessary for the underwater positioning system on both the ROV and research vessel (Brandvik, 1998).

FlemingCo environmental, Denmark, has proposed to Bitor Corporation the use of sonar for the underwater remote detection of spilled orimulsion. Conclusions of a literature study – mainly based on the observed success of the SINTEF efforts –led Bitor Corporation to sponsor a small scale tank test of a spilled orimulsion underwater remote detection and monitoring system using acoustic means. A 455 kHz multibeam forward-looking sonar was tested. The tank test, which was conducted by Fleming Hvidbak of flemingCo, occurred at a Danish refinery on April 27, 1999. The sonar detected and monitored the Orimulsion cloud for 45 minutes after the release of eight liters of orimulsion at a depth of 0.75 m in a 25 x 5 x 1.5 m (L x W x D) tank. The orimulsion cloud was approximately 17 m away from the sonar (Hvidbak, 1999).

Sonar has also been suggested as being feasible by experts from SIMRAD, a manufacturer of sonar and echo sounding equipment (Uzzell and Andersen, 1999).

7.3.4 Surface Oil Surveillance and Monitoring

After the oil reaches the sea surface, tracking can be accomplished using existing visual and electronic systems deployed using fixed wing aircraft and helicopters. The usefulness of these systems may be limited by the remoteness of deepwater drilling sites from land and the ability of aircraft to maintain station or track oil over a large area with a limited fuel supply. This potential problem might be overcome or aided by the use of space based imaging systems as discussed in Section 9.3.4.

7.4 Recovery of Oil on the Sea Surface

In addition to the research conducted on subsea collectors after the Ixtoc 1 blowout, MMS funded the design and cost analysis of a ship-mounted surface collector for use during offshore blowouts (Stewart Technology Associates, 1987). The system design required a retrofitted tanker with dynamic positioning capability situated downstream from the blowout. Two work boats deployed boom on either side of the ship to form a W-shaped collection system. The collected oil would be recovered into the tanker for treatment, storage and later transfer to another vessel. The design called for the tanker to be equipped with a recovered oil processing system, dispersant spraying capability (via shipboard helicopter), extra booms, and a spill command center. As with the ship-mounted subsea collector described in Section 7.1.3, no research on this system has been performed since the 1987 report. The use of a dedicated tanker hull retrofitted to collect spilled oil makes the approach impractical and expensive given the low probability of blowout occurrence. The most serious limitations of the system are its cost, and the fact that multiple systems would be required to provide coverage off different coastlines. Additionally, the amount of spill response equipment available to industry has dramatically increased since the passage of OPA 90, making the study results near obsolete.

Surface oil spill clean up will have to rely on conventional methods and will likely have to make use of mechanical oil spill response equipment. The main hurdle will be of a logistic character if vast amounts of oil reach the surface. If, for example, a stable water-in-oil emulsion is formed with 20% oil content (MSRC, 1993) from an oil well producing 10,000 bbls/d one may potentially have to deal with 50,000 bbls/d of emulsified oil. Even discounting emulsification, the Deepwater Well Control Guidelines (International Association of Drilling Contractors, 1998) cite a worse case deepwater well blowout of 30,000 to 40,000 bbls/day. Compounding the logistics problem is the fact that deepwater oil fields are located farther offshore and farther from the sources of most spill countermeasures. For example, Shell's Auger platform is located approximately 255 miles southeast of Houston and 214 miles southwest of New Orleans. The greater distances may have implications with respect to the OPA '90 tier response times and the ability to support mechanical spill response efforts in the early hours of a response. The greater distance, however, will allow responders more time to prepare before there is a threat to a shoreline.

Storage of recovered oil may limit any recovery operations at deepwater blowout sites unless provisions are made to handle the large volume of recovered fluids and separate the oil from the water on the oil spill response vessel (OSRV) or storage vessel. Currently, only the Marine Spill Response Corporation's OSRVs have recovered oil systems capable of breaking emulsions and with oil water separators that will meet 15-ppm discharge standards.

Approximately 58% of the oil spilled by the IXTOC I well blowout was burned off at the surface (International Association of Drilling Contractors, 1998). If ignition of the surface oil is possible, and it can be burned in a controlled safe manner, it should be ignited, and every effort made to maintain the burn. The weathering properties of the oil, discussed in Section 7.2.2, will assist in determining if burning is an option. The ability to contain and sustain a controlled burn has not been demonstrated for remote offshore locations.

7.5 Problem Summary

For subsea oil containment the technical hurdles to be overcome during a deepwater blowout include:

- Predicting the behavior of deepwater currents
- Ability to manipulate heavy objects on the sea bed
- Ability to design subsea collectors that are flexible enough to cap a large range of subsea wellhead assemblies and accommodate a high volume of recovered oil, gas and water
- Ability to approach the blowing well and install containment devices on the seafloor
- Lack of standardization in subsea wellhead design

For subsea dispersant application, these include:
- Availability of equipment and methods for delivering the dispersants to the plume

For oil remote sensing and tracking, these include:

- Lack of understanding of plume dynamics
- Lack of information on oil properties
- Methods for detecting submerged oil plumes
- Limited usefulness of surface oil surveillance and monitoring aircraft

For recovery of oil on the sea surface, technical hurdles include:

- Logistical problems for mechanical systems dealing with large quantities of recovered oil and water at locations far offshore
- Ability to contain and sustain a safe, controlled burn at remote offshore locations has not been demonstrated

Likely solutions to each of these problems are developed in Section 9.

8.0 Blowout Patent Search

To ensure that solutions to the technical hurdles identified in Section 7.0 did not already exist, patent searches were performed in both Norway and the U.S. for blowout containment devices. Patents, which were thought to have potential application to provide deepwater containment, or which might have application as a spill countermeasure were copied for evaluation. The blowout scenarios developed in Section 4 were used to evaluate the usefulness of the patented idea. Each patent was then assigned a classification using the following classification numbers to evaluate the technical and economic viability of the different ideas in the patents:

1	Strongly water depth dependent. Can not be used in deep water
2	Plume dependant. Behavior of plume may effect collector viability.
3	Technically viable, but needs research and verification testing
4	Technically not viable due to handling and operation considerations
5	Economically not viable due to size, complexity and cost of operation
6	Standardization impossible for use with any sub sea installation

The results are summarized in Tables 7 and 8. Comments on those that appear to be technically viable, but need further research and development, are provided in Section 9.1.3.

8.1 U.S. Patents

The U.S. patent search was conducted in the following manner. A search was conducted using the U.S. Patent and Trade Office web site (http://patents.uspto.gov) with the key words blowout, recovery, submerged oil, and oil spill. From this site it is possible to obtain copies of patent abstracts and numbers dating back to 1968. Using these, and patent numbers from the earlier literature search performed by Brown and Root (Brown & Root, 1985), copies of the patents were obtained at the U.S. Patent and Trade Office in Arlington, VA. The references cited in the patents were then reviewed, and copies were made of those earlier patents that contained additional information that might be of use in developing potential solutions for deepwater blowouts.

Patent no.	Name	Description	Classification
3,389,559	Fluid recovery system and method	Flexible sheet designed to contain the oil on the surface in a certain area	4
3,548,605	Submersible vehicle for emergency offshore gas leakage	Submersible support frame with collapsible reinforced fabric to direct the flow to surface.	2,3,6
3,599,434	Device for confining oil released by leakage.	Deep skirted boom concept	1
3,643,741	Sealing of underwater fissures	Well control by using polymerizing chemicals	Not applicable
3,653,215	Confining and collecting oil leakage	Surface deployed flexible fabric similar to 3,548,605	1,2,4,5
3,658,181	Underwater oil leakage collecting apparatus	Device for directing flow into a floating structure	1,2
3,667,605	Submerged oil leak control	Early version of the inverted funnel concept	2,4,6

Table 7

3,674,150	Apparatus for preventing offshore oil well pollution	Variation of the inverted funnel concept	2,4,6
3,681,923	Apparatus for controlling subnatant oil seepage	Fixed structure extending from the seafloor to the surface	1
3,719,048	Offshore structure with static dynamic stabilization shell	Submersible inverted dome	5
3,746,097	Subsurface blowout prevention	Down hole BOP system	Not applicable
3,760,891	Blowout and lost circulation detector	Method to detect a blowout development	Not applicable
3,738,424	Method for controlling offshore petroleum wells during blowout conditions	System for injection of gas to develop an ice plug in the well	Not applicable
3,813,887	Apparatus for removing liquid contaminants from a submerged tank	Apparatus for hot tapping into a tank and remove fluid	Not applicable
3,861,470	Method and apparatus for inside blowout preventer drilling tool	Blowout preventer mounted inside the drill string	Not applicable
3,879,951	Underwater drilling pollution control curtain	Flexible fabric sea curtain	1
3,885,629	Method and assembly for controlling blowout in oil wells	System for injection of CO2 to an oil well thus creating an ice plug	Not applicable
3,926,256	Methods and apparatus for controlling and preventing blow out in wells	Method for injection of seal material in an oil well	Not applicable
3,981,154	System for recovering petroleum fluids from underwater fissures	Inverted funnel in flexible material moored to the seabed	2,4,5
4,163,477	Method and apparatus for closing underwater wells	Method for remote closing of underwater wells by divers	1
4,283,159	Protective shroud for offshore wells	Fixed piled system to create an enclosure around a fixed platform	1
4,309,127	Apparatus for controlling submarine leakage	Fixed structure from the sea bed to the surface to contain oil spill	1
4,318,442	Apparatus for controlling an underwater blow out	Classic inverted funnel deployed from a large barge	5,6
4,323,118	Apparatus for controlling and preventing oil blowouts	Inverted funnel with valves located on the seabed	5,6
4,336,843	Emergency well-control vessel	Dedicated semisubmersible vessel for well control	4,5,6
4,324,505	Subsea blowout containment method and apparatus	”Sombrero” approach well documented	2,4,5
4,358,218	Apparatus for confining the effluent of an offshore uncontrolled well	Bottom mounted collector tank	2,4,6
4,373,834	Portable offshore well installation apparatus	Flexible skirt from seasurface to the sea bed	1
4,382,716	Blowout recovery system	Inverted funnel with extended tubes for oil recovery	1

Table 7 (continued)

4,421,436	Tension leg platform system	Installation of tension leg platform over the blowing well. Tension wires used for supporting the collection unit	3 (5)
4,456,071	Oil collector for subsea blowouts	Collector launched from a jacket platform	1
4,531,860	Deep sea oil salvage means	Bottom mounted collection chamber with hoses to the surface	4,5,6
4,568,220	Capping and/or controlling undersea oil or gas well blowout	Remote operated robot operating on preinstalled rails.	3,5,6
4,643,612	Oil clean up barge	Surface mounted dedicated barge for surface oil collection	1,2,5
5,195,842	Oil spill tent	Oil spill collection tent mounted between the sea bed and surface	1
5,213,444	Oil/gas collector/separator for underwater oil leaks	Surface mounted collector tank	1,2,5
5,289,883	Well casing-contained blowout preventer	Casing mounted blow out preventer	Not applicable
5,704,732	Deep water piling method	Suction anchors as piles for subsea structures as inverted funnels	6

Table 7 (continued) - Summary of U.S. Patents

8.2 European Patents

Our Norwegian team members at NOREN A/S conducted the patent search for European patents. These were reviewed, evaluated and ranked by PCCI and NOREN using the same classification numbers shown in Section 8. Patents from Norway, France and the UK were located and are summarized in Table 8.

UK Patents

Patent no.	Name	Description	Classification
E02B 15/04 E21 43/01	Equipment for the recovery of oil flowing out of sub-water ground	Surface mounted separator system with flexible skirt to the sea bed	1,2,5
1.601.462	Improvements in the control of oil and gas well blowout	System to improve the gas and oil mixing in conjunction with the use of a subsea collector unit	Not applicable
2.063.776	Apparatus for subsea collection of oil leakage	Sub sea collector bell	1
2.134.159	Safety installation for a submerged drilling well head	A remote controlled safety system to prevent blow out	3 (5)
2.150.614	Diverter/BOP system for a bottom supported offshore drilling rig	Surface mounted safety system during drilling	Not applicable
2.254.632	Controlling damaged wellheads	Clamp on system for installation on damaged well heads	Not applicable

Table 8

French Patents

2.368.581	System for subsea collection of oil from a blowing well	Anchored bottom tent structure	1,2
2.488.927	System to collect oil on the surface	Flexible oil boom construction on the surface to enclose the oil from a blow out	1,2
2.463.835	System to guide the oil from the blowout to the surface	Subsea tent structure. Same as US patent no. 4.421.436	2,3

EU Patents

WO 9216714	Apparatus and method for suppressing an uncontrolled blow out	Valve arrangement for BOP	Not applicable
E 02B15/04	Apparatus for confining and controlling a flow of fluid from a blowout	Heavy structure to be mounted around the flowing well and piled to the sea bed by explosive piles.	2,4,6

Norwegian Patents

139527	System for submerged oil boom	Submerged oil boom which can be submerged by means of adding air and water as ballast	1
139749	Apparatus for protection during blowouts	System in use with large concrete gravity platforms	1
140143	Apparatus and method to influence the characteristics of the plume	System to be mounted on top of the BOP in order to direct the plume to the surface.	1
145155	Apparatus to collect oil from a subsea blowout	Remote operated subsurface structure to encapsulate the blowing oil well	5,6
146545	Apparatus and method to collect oil from a subsurface blowout	Subsea dome to collect and direct the oil and gas flow to the surface	1,5,6
149513	Apparatus to collect oil from a subsea blowout	Subsea dome system	1,5,6
149641	Apparatus and method to collect a flowing fluid without control	A subsea dome located on the seabed with pressure relief system and gas separator	1,5,6
150368	Apparatus to collect and guide fluid and gas from a subsea blowing well to the surface	Subsea dome with hose connection to the surface with a surface mounted combined pressure relief system and separator.	1,5,6
151976	Apparatus and method to collect oil from a subsea blowing oil well	Flexible tent structure to be located above the sea floor	1
152948	Method to control a blowout from a subsea oil well	Well intervention system.	1
153816	Apparatus to collect fluid from a subsurface source	Surface mounted dome structure with inverted funnel to collect oil.	4,5
153938	Apparatus and method to collect oil and gas.	Subsea dome structure with pressure relief system	1,6

Table 8 (continued)

156300	BOP system	A system for back up control system for the BOP	Not applicable
176813	Oil collector	Subsea anchored tent structure	1
802126	Inverted funnel for oil collection	Bottom mounted inverted funnel system	1,6
803032	Apparatus to collect oil from a subsurface source	Large dome structure	1,6
801409	Method to collect oil from a subsea oil well	Dome structure operated on existing guide wire system	3, 6(?)
860135	Method to collect oil from a subsurface oil leaking source	Seabed mounted dome structure	1,6
891613	Oil boom system	Oil boom constructed on scene by freezing water using liquid gas	4,5
900571	Method to apply dispersant and absorbents subsurface	System to apply absorbents or dispersant to a subsurface oil slick	2,3
912146	Subsurface oil collection unit	Subsurface oil collection tent structure	4
941998	Oil barrier structure	Tent structure mounted on the seafloor	1

Table 8 (continued) – Summary of European Patents

9.0 Potential Deepwater Blowout Countermeasures

The patent searches identified seven patents that warranted further investigation. Six of these are for subsea collectors that suffer from the technical hurdles identified in section 7.1.3. Most of these would only be applicable to specific blowout scenarios or wellhead equipment types (i.e single wellhead/stacks). The other patent describes a method for application of dispersants or absorbents to oil in the water column. The six subsea collector patents warranting further investigation are summarized in Section 9.1.3.

Since the patent search results were not particularly useful in solving the technical hurdles to deepwater oil spill response identified in Section 7, literature searches and brainstorming sessions among the team members were used to develop potential technical techniques and equipment that might be used to solve the technical hurdles. The following sections describe these possible techniques and existing equipment that might be further developed as deepwater oil spill countermeasures. The subject and order in which they are presented match the Section 7 description of technical hurdles to deepwater oil spill response.

9.1 Subsea Oil Containment

9.1.1 Deepwater Currents

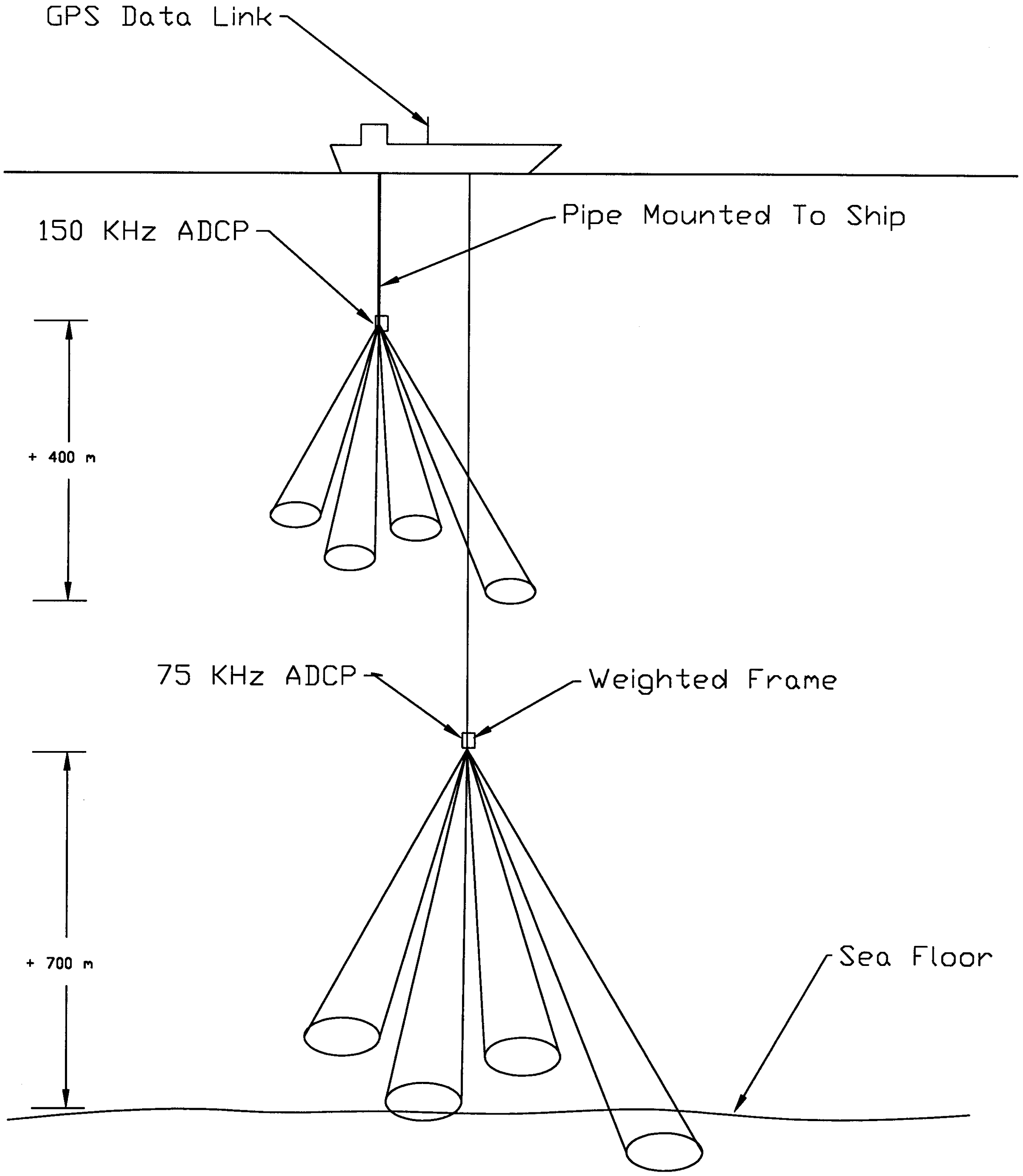
Predicting the behavior of deepwater currents will be required for relief well planning, tracking of released oil, and installation planning for subsea containment. Measured ocean current profiles and vertical sea temperature and salinity profiles are required as input to simulation models for deep water blowouts.

Tracking deepwater currents has primarily been of interest to academia and the world’s navies instead of its oil companies. The technologies for deepwater current tracking can generally be divided into three categories: those using acoustic tracking, those using neutrally buoyant floats, and those using a combination of acoustic tracking and neutrally buoyant floats. None of these has been tried to track oil released from deepwater blowouts.

Acoustic Doppler Current Profilers (ADCPs)

The real-time measurement of current data from the surface to water depths of 1,863 meters using two ADCPs was described in a recent technical paper (Hamilton, Vogel and Noda, 1990).

In order to cover the full water depth range for this test, a 150 kHz ADCP was mounted below the support vessel, and a 75 kHz ADCP was towed in a frame at depths of up to 1300 meters (see Figure 20). A 150 MHz unit was used near the surface to prevent interference with the 75 kHz unit. Its use reduced the coverage of the current profile by approximately 300m, but a gap of that magnitude in the middle of the current profile was acceptable for their cable laying operation. The 75 kHz ADCP was mounted in a specially built aluminum frame that was attached to 6000 ft of well logging cable spooled on a slip-ring equipped winch mounted on the support ship. This arrangement allowed the ADCP to be towed to depths of up to 1400m while keeping the ADCP approximately 700 m above the bottom (the 75 kHz ADCP was used in the bottom tracking



Arrangement of the two acoustic Doppler profilers on the support vessel.

Figure 20

mode). The average depth ranges of the 150 kHz and the 75 kHz units were approximately 400m and 700 m respectively. The data from these two ADCPs were corrected for the ship's velocity and tow frame velocity. A central processing computer with output to a data acquisition system, which received ship position and tow frame depth data to provide a true current profile, controlled quality. This system was quite complex and detailed planning and testing of the system were vital factors in making the current measuring system work successfully. Only with similar planning and testing, a deepwater ADCP system might be developed and kept ready for deployment to track deepwater currents during a blowout.

Neutrally Buoyant Floats

Neutrally buoyant subsurface floats are less complex but unless coupled with acoustic tracking do not provide real-time current data. The Autonomous Lagrangian Circulation Explorer (ALACE) is an example of a neutrally buoyant subsurface float which surfaces at regular pre-determined intervals to transmit temperature and pressure data, and be positioned by a satellite GPS system before returning to its operating pre-determined depth. It was developed for applications where acoustic tracking of buoys is not an option (Gould, 1998). There is no way of knowing, however, where the buoys are until they surface. ALACE floats have been built to carry a conductivity, temperature, depth (CTD) sensor packages and measure and transmit profiles of temperature and salinity each time they surface. There are currently 17 ALACE floats in the Gulf of Mexico operating to about 900 meters depth as part of the National Ocean Partnership “Gulf of Mexico Ocean Monitoring System”.

The Autonomous Profiling Explorer (APEX), like ALACE, is an autonomous drifting profiler. Unlike ALACE, the APEX features active depth control, and can profile up or down from its drift depth. Webb Research Corporation manufactures both drifters. Data sheets on ALACE and APEX floats are included as Appendix A. The ALACE floats cost approximately $10,000 each without CTD sensors (Webb, 1998).

Floats with a continuous sound source or with acoustic receivers on the floats, where the sound source is moored nearby, have also been developed for float tracking from an attending ship or using the Navy's SOund Fixing And Ranging (SOFAR) channel to a shore based listening station. The floats with acoustic receivers, known as RAFOS floats (the inverse of SOFAR) uploads the signal arrival times used for float tracking to a satellite system when the float surfaced at the end of its trajectory. These systems might also have application for tracking oil from deepwater blowouts but are much more complex than the ALACE floats and near the well might be hampered by the acoustic interference described in Section 7.1.4.

Tests of the usefulness of ADCPs and neutrally buoyant float systems should be performed and operational methods developed for the deployment and use of the system best suited for use at the time of a deepwater blowout. Additionally, these systems can be used to collect deepwater current data which should be incorporated into spill response plans.

9.1.2 Manipulation of Heavy Objects

The best options for blowout spill containment may be in the areas of well control (which are outside the scope of this study) and technologies for speeding the process of natural degradation of the released oil using dispersants applied at the wellhead (see Section 9.2). Both will require

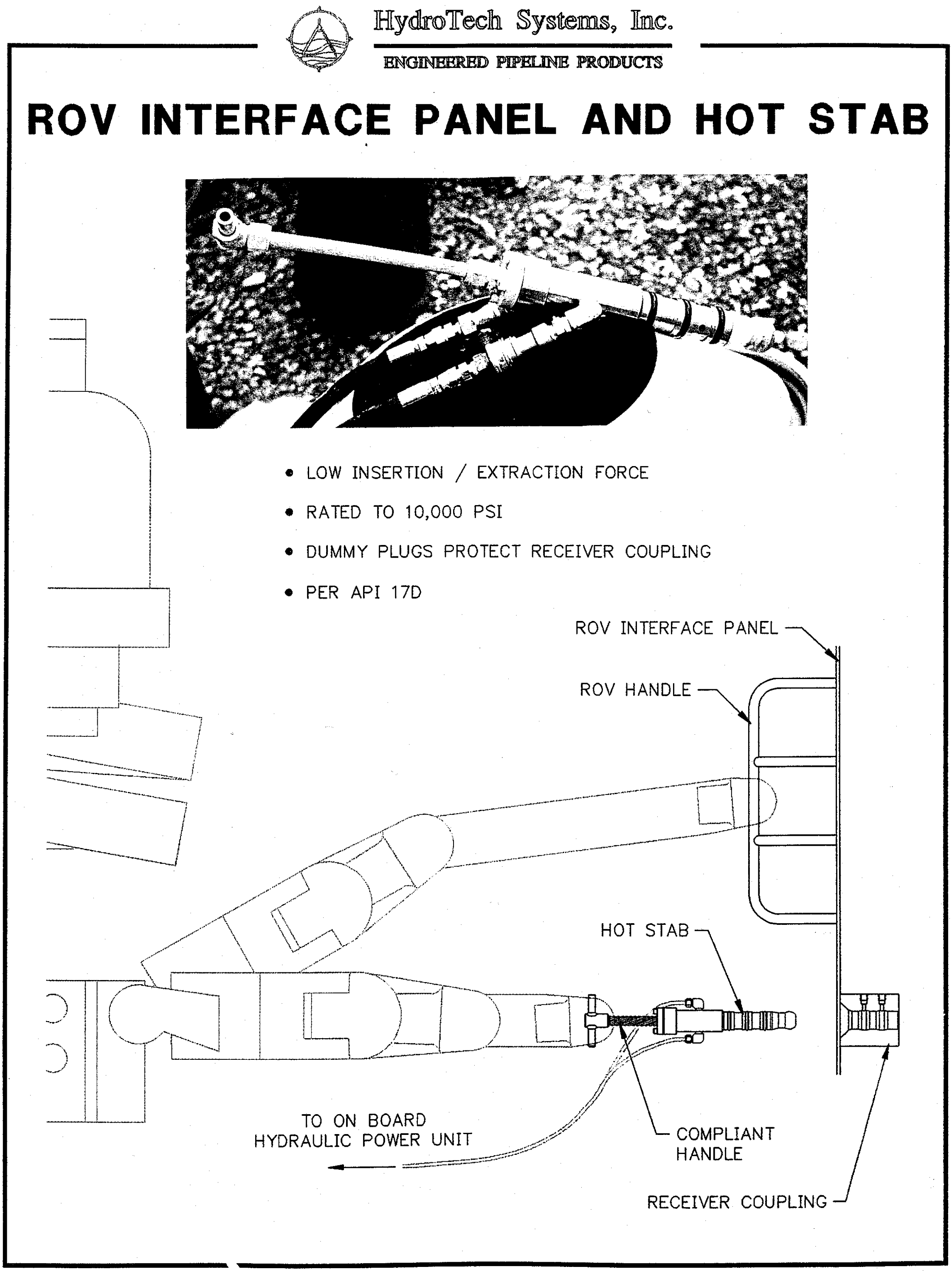
the manipulation of heavy objects near the seafloor. Manipulation of heavy objects will be required to promote self closure of the oil well by bridging, or to install subsea collectors.
The merits of enforced bridging must be determined by well control specialists. The method can not be standardized and has to be evaluated in each single case. Removing flow restrictions may help enforce bridging. In order to evaluate this option in ultra deep water well control specialists will need deep water suitable remote controlled tools as described below. Additionally, the removal of flow restrictions to promote bridging will likely require regulatory approval, as it is similar to allowing the purposeful discharge of oil from a tank ship in order to prevent the total loss of the tanker and a larger spill.

Intervention at the wellhead will require the capability to place and /or remove large equipment as described in Section 7.1.2. Conventional ROVs do not have a heavy object manipulation capability. They can be used to make or break connections and assist with the recovery of objects on the seafloor. If they can lock on to a fixed object, they can be used to replace ring gaskets, BOP control hoses, and actuate hydraulic functions with ”hot stabs” (See Figure 21). ROVs can be used to re-establish guide wires or guide posts if they can get close enough to the BOP stack without becoming entrained in the blowout plume; however, they tend to have short arms which would not allow them to get close to a blowing well.

The blowout site will normally be close to the seabed which could provide a base for a new type of crawling ROV. A concept for such a system is described in Appendix B. A remotely operated seabed based vehicle with a long manipulator arm may have the ability to assist with the deployment of subsea oil contiainment devices, or intervene at the BOP by cutting and capping stab-in connectors to the kill and choke line. The unit could be equipped with a long manupaltor arm with a reach of up to 45 ft. In order to withstand strong inflow currents and blowout turbulance, the vehicle should be heavy. Weight is not a significant restriction as the operational mode for the vehicle will be on the sea bed, and it does not need free swimming capability. A suitable unit will be equipped with mulitple tools for cutting and advanced manipulator arms for attachment of wires for surface assisted heavy lifts. As described in Appendix B, the vehicle will operate from a fixed installed platform at a maximum distance of 300ft from the blowout point. The platform will contain all necessary control systems and an electro hydraulic powerpack. Power from the surface will be supplied through a standard umbilical transferring electricity at 7000 volt current. Hydraulic power can be supplied from the subsea platform to the working vehicle by a flexible umbilical containing hoses for high and low pressure hydraulics as well as signal cable for operation of onboard solonid valves. Transfer of power for BOP system over-rides, repair, or to power underwater tools can be accomplished using ROV hot-stabs. Danfoss A/S has recently introduced a series of water hydraulic components (using the tradename Nessie7) and in the future subsea equipment might be powered by water.

9.1.3 Subsea Collectors

Patents from the search described in Section 8 that were thought to have technical merit for deepwater application are summarized below. These devices would require further research and development to overcome the technical hurdles described in Section 7.1.3.



HydroTech Systems, Inc.

ENGINEERED PIPELINE PRODUCTS

ROV INTERFACE PANEL AND HOT STAB

- LOW INSERTION / EXTRACTION FORCE
- RATED TO 10,000 PSI
- DUMMY PLUGS PROTECT RECEIVER COUPLING
- PER API 17D

Figure 21– ROV Interface Panel and Hot Stab

9.1.3.1 Submergible Vehicle For Emergency Offshore Gas Leakage

Patent #: U.S. No. 3,548,605
Date: 12/22/70
Inventors: Peter L. Paull and Fontaine C. Armistead
Abstract: Submersible support frame with a self contained collapsible reinforced fabric conduit to direct the flow to the surface where the oil can be recovered or burned.
Comments: This concept deserves further research and development to study environmental and deployment loads, and costs. It has potential for application to single well subsea structures and minor leakage from a well. Its merits are that it would be relatively lightweight compared to inverted cone concepts, simple in principle, and could be quickly deployed. Its drawbacks are that sizing of support frame to enclose well templates of various sizes would be necessary, and the effects of weather on the surface containment device might be prohibitive.
R&D Required: Flexible conduit dynamics, installation procedures for ultra deep water, control systems for ascent of the column to the surface, pressure and pressure balance on the conduit, and recovery methods after use.

9.1.3.2 Tension Leg Platform System

Patent #: U.S. No. 4,421,436
Date: 7/6/82
Inventor: Robert B. Burns
Abstract: A tension leg platform system for collection of oil leakage from a subsea structure that incorporates a submergible hull that can be controllably lowered down the tension leg members to the ocean floor with a canopy to cover the uncontrollably flowing well and conduct the effluent to the water surface.
Comments: The patent has some potential when used with a tension leg platform. The tension wires will form a fixed connection to the seabed and may secure the invention. Oil and gas may be directed to the surface by a large riser connected to the top of the tent like structure.
R&D Required: A reliable method for installation and operation, and a method for transportation and storage of the structure have to be developed. Fluid dynamics and plume formation will be deciding factors it is questionable if the tension leg platform will remain in position in case of a major blowout.

9.1.3.3 Capping and/or Controlling Undersea Oil Or Gas Blowout

Patent #: U.S. No. 4,568,220
Date: 3/7/84
Inventor: John Hickey
Abstract: Describes a system for capping and controlling a blowing BOP or wellhead. The system contains a seabed rail mounted remote operated vehicle with heavy lift capability. A special clamp capping system is proposed. The vehicle will move on the seabed on the preinstalled rails and enclose the blowing well by the use of a special clamp on dome.
Comments: The invention is based upon the assumption that it will be possible to establish a new practice for subsea installation. A new type of well structure with a rail system has to be

installed as part of the well structure. The remote operated vehicle will be installed on the rail once a blow out occurs. The system would be part of a special contingency system for blowouts. The system will only be possible to use if the leaking oil is coming from the BOP or the well head itself.
R&D Required: A System for multiple wellheads has to be designed, a cost benefit analysis will have to be carried out, it might be possible to develop the concept further in order for it to be more versatile

9.1.3.4 Wire Supported Collection System

Patent #: FR No. 2,463,835
Date: unknown
Inventor: unknown
Abstract: This patent is similar to US patent No. 4.421.436. The tent like structure is supported by 4 floating structures. These are connected to the sea floor and act as supports for the structure.
Comments: See comments to US patent No. 4.421.436
R&D Required: See comments to US patent No. 4.421.436

9.1.3.5 Safety Installation for a Submerged Drilling Well Head

Patent #: U.K. No. 2,134,159
Date: 4/4/72
Inventor: Georges Vigouroux, Gilbert Fort, Louis Marie Soleille
Abstract: Describes a predesigned system for emergency intervention to the oil well. A predesigned well head will make use of a remote located umbilical drum located on the seabed at some distance from the well. By using a drill string from the surface, a hose may be connected to the wellhead through a stab-in connector. The drill string will connect to the hose drum structure and thus establishing connection to the wellhead for injection of well kill fluid.
Comments: The invention is based upon the assumption that it will be possible to establish a new BOP design practice. The new BOP design will have to include stab in connection for access to the kill and choke line. The system will also be dependent upon the availability of a suitable advanced deep ocean drilling vessel. Once the system is established one will thus be forced to choose between well intervention and drilling a relief well.
R&D Required: A new BOP design practice would have to be established, and new operational procedures would have to be established.

9.1.3.6 Apparatus and Method to Collect Oil from a Blowout

Patent #: NO 801409
Date: 5/13/80
Inventor: Fred H. Kooka, David Culver
Abstract: Describes a system consisting of a subsea dome structure with a surface collection system. The dome structure makes use of the existing guide posts and guide wires on a subsea template.
Comments: The invention differs from other dome structures in the operational description of the system. It may be used if the blowout comes from the BOP and if there is no damage to the

structure on the seabed. It also requires existing, intact guide posts and that the BOP is located on a subsea template. The dome is lowered on guide wires or by using a drill string. It enters the existing guide posts and locks to the subsea template. The operation may be applicable if there is a minor leak from the oil well.
R&D Required: Methods for deep sea installation would have to be investigated, operational procedures and methods would have to be developed, and flow characteristics would have to be determined

9.1.4 Installation and Approach

The blowout plume will make it difficult to approach the well with anything but very massive equipment pieces or ROVs. The operation of ROVs will be difficult around the blow out point. The jet zone will cause vast amounts of water to flow towards the well.

The installation of any subsea collector must be coordinated with well control personnel to ensure that there is no interference with ongoing well control operations.

The potential for acoustic interference to navigation systems from a blowout needs to be researched further to determine the best possible solution. Potential solutions include the use of an inertia navigation system (as proposed for the multipurpose deepwater crawler in Appendix B), or possibly tuning the acoustics to a bandwidth not affected by the release of gas. The University of Liverpool has reportedly worked on the use of underwater RF transmission for application to positioning a deepwater ROV with respect to its deepwater docking station. Fine tuning of this system is expected to occur during basin tests in France (Offshore, 1998). Development of this system should be monitored for potential application to this problem.

9.1.5 Standardization

The lack of standardization in subsea well head and BOP design and operations can only be addressed through the development and application of well conceived standards for subsea equipment. These standards must address the design of both the subsea well equipment (i.e. overrides) and ROV equipment and tooling. One option is the proposed API 17H Single Point Docking Unit shown in Figure 22 (Frisbie, 1998) which would standardize the equipment modifications required to optimize ROV support capabilites by addressing the location and type of docking/handholds, marking and identifiction criteria for low visibility operations, and the design and orientation of selected overide functions.

Figure 22 – Single Point Docking Unit

9.2 Subsea Dispersant Injection

Enforcing the dilution of the released oil in the water column, in order to speed natural degradation, by injecting dispersant into the well or into the jet zone of the blowout is one of the most promising spill countermeasures identified.

Two concepts for the injection of dispersants into a blowout plume were developed earlier and are presented in the DEA –63 Report (Neil Adams firefighters, Inc., 1991). One of the concepts required the installation of a special injection spool or port for dispersant injection in the subsea stack or BOP itself (see Figure 23). An injection hose would lay on the seafloor connected to a pendant buoy which could be recovered by a vessel of opportunity and the dispersant could be pumped into the plume. Another concept showed the dispersant injected from the wellbore through a tube connected to a side pocket mandrel or down an open annulus in a platform drilling operation (Figure 24). Both of these concepts require pre-planning to incorporate equipment for dispersant injection into the design of drilling and production equipment.

Neither concept would work for the scenario invoving a broach, or if wellhead/stack is not intact or the injection line has been damaged. Thus the report recommended the development of a wellhead independent device that would be simple, easy to fabricate , transport and install with little additional technological development. The cone shaped flow through device shown in Figure 25 was recommended, with nozzles arranged around the periphery at the top of the opening for injection of the dispersant. The device would be anchored over the blowout source.

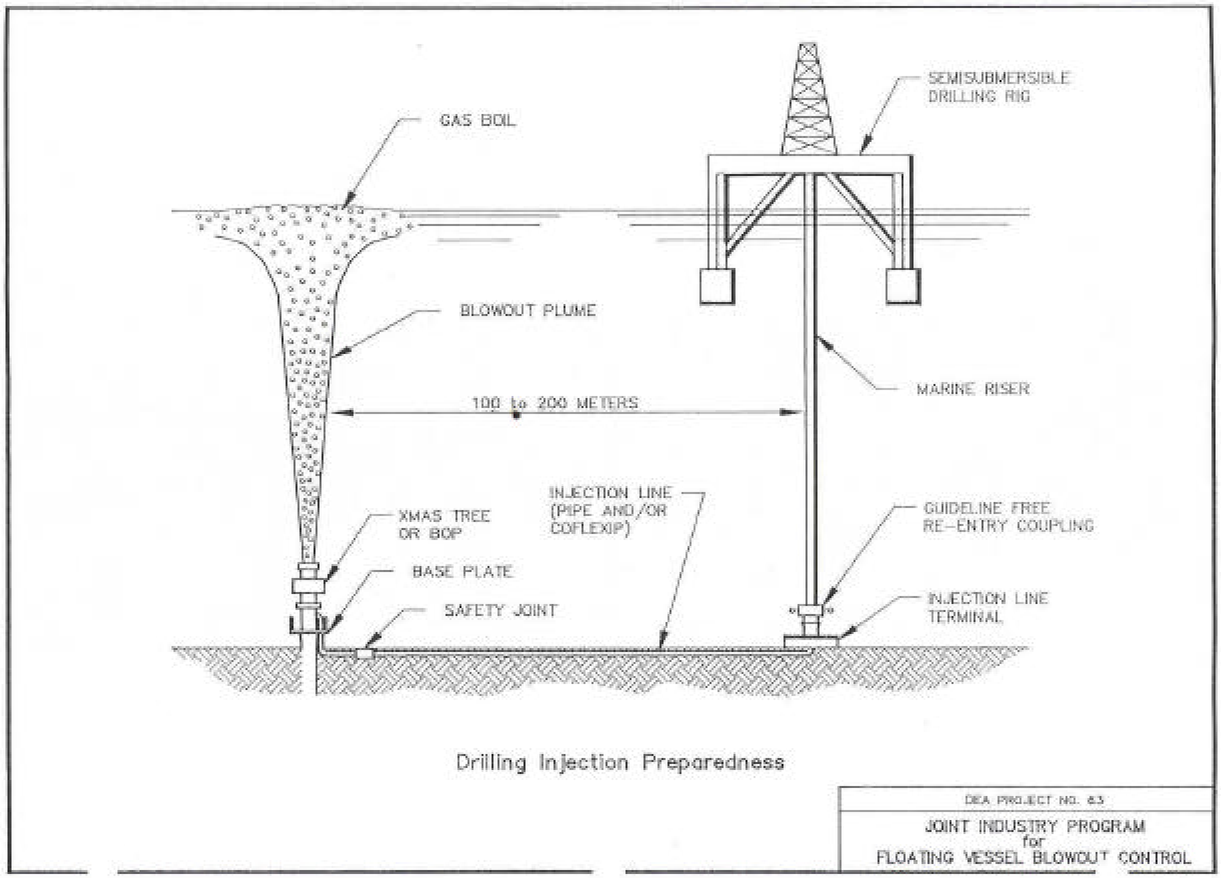


Figure 23 – Concept For Subsea Dispersant Injection At The Wellhead

The top of the device would behave like an educator. The dispersant would be drawn into the plume by the venturi effect. An advantage of this design is that the shape of the device would allow vertical intervention well control methods to be used while the effluent is being treated. As this device could be used in all of the subsea release scenarios developed in Section 4, it could be constructed as blowout contingency equipment item that could be stored along with adequate stocks of dispersant in an OSRO's inventory.

Subsea testing of dispersant injection into a blowout plume is required to validate this as a potential blowout oil spill countermeasure. Equipment and methods for the delivery of dispersant to the blowout source require developed. Further research is required to to determine the injection nozzle design, methods and ratios for subsea dispersant injection to be effective and take advantage of plume dynamics to enhance mixing. For the device shown in Figure 25, the number and size of nozzles needed for adequate dispersant for a given throat diameter; a suitable anchoring system; storage tank dimensions; and dispersant supply pumping, monitoring, and control systems; would need to be designed and tested.

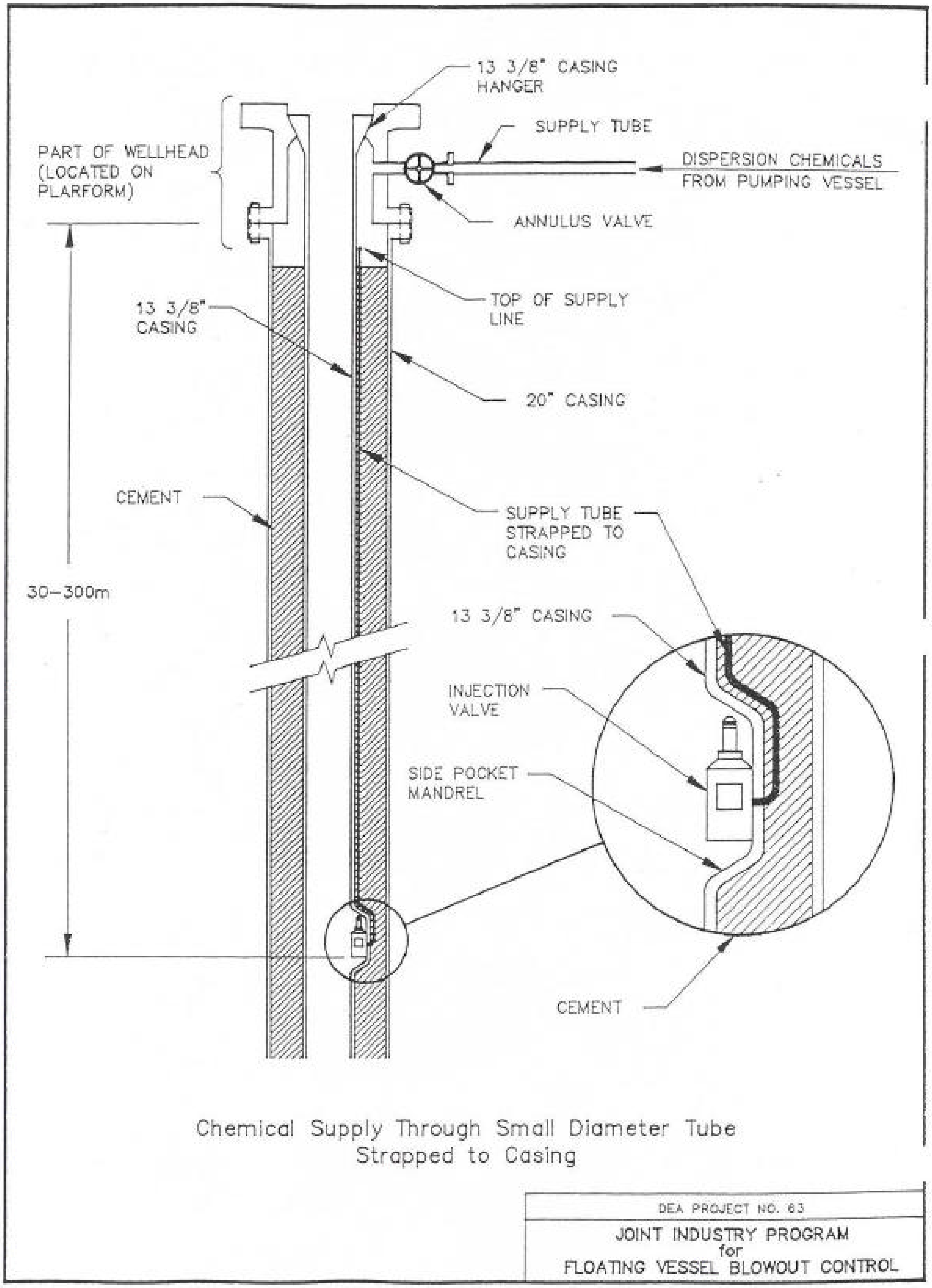


Figure 24 – Concept for Subsea Dispersant Application in the Casing

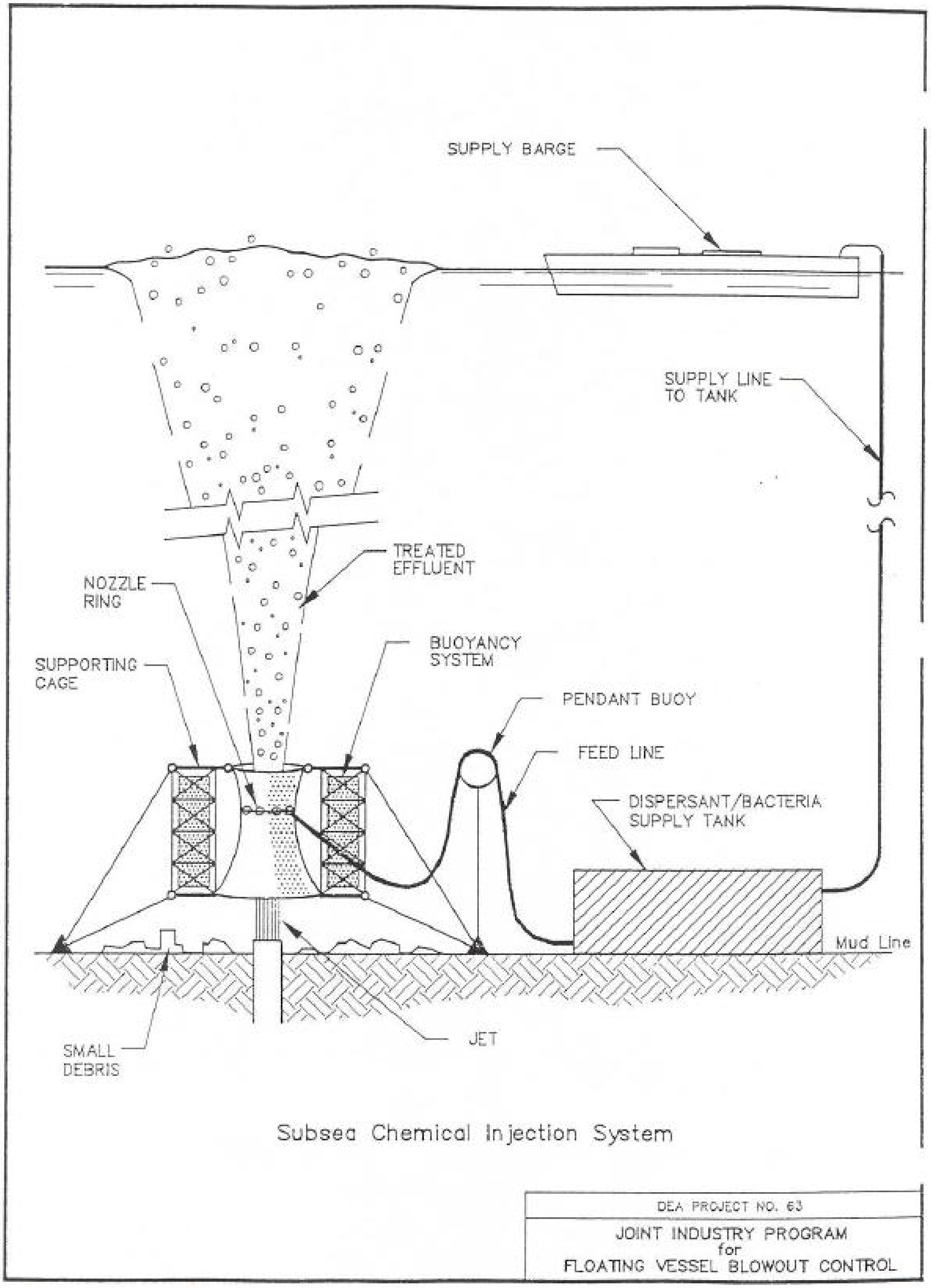


Figure 25 – Concept For Wellhead Independent Subsea Dispersant Application

A remotely operated seabed based vehicle, as described in Appendix B, with a long manipulator arm could also be designed to have the capability to use nozzles for injecting dispersant directly into the jet zone of the blowout.

9.3 Oil Remote Sensing and Tracking

9.3.1 Understanding of Plume Dynamics

As noted in Section 7.3.1, the ability to model and predict plume dynamics, for tracking the oil released from a deepwater blowout, should be a priority research area. This is especially true for ultra deepwater, since present computer blowout models are relatively simplistic and cannot model the effects of high pressure, hydrate formation, subsurface currents, and stratification.

Modeling

Research efforts to expand the capabilities of subsurface blowout and release models are planned or underway at organizations including Applied Science Associates, Inc. (Spaulding, 1998), Chevron (Alan, et. al., 1997), Clarkson University (Zheng and Yapa, 1999), and SINTEF Applied Chemistry. Sufficient data to validate the predictions are the key for any model to produce realistic results. Efforts are underway to collect both experimental data (University of Hawaii, 1998) and offshore test release data, and these should be an integral part of any model development effort. Offshore test releases would also be an opportunity to test the equipment described in Sections 9.1 and 9.2 (i.e.: equipment for current tracking, manipulating heavy objects, and subsea dispersant injection) and the equipment described below for real time imaging of a blowout plume.

Real Time Imaging

It should be possible to make measurements of a blowout's plume jet zone diameter and height using sonar and other sensors. Images of the formation fluid flow can be compared to known dimensions on the BOP stack. High speed images of the plume can be used to estimate velocity by using bubbles or other discontinuities in the flow and measuring distance traveled between successive pictures (International Association of Drilling Contractors, 1998).

SINTEF used an ROV equipped with a sonar operating in the 450 – 650 kHz range during their underwater releases of oil in 1995 and 1996 (Brandvik, 1998). The sonar was commercial equipment made for fish finding. Pictures from the sonar, and a low light camera, were used to quantify the diameter and position of the plume relative to the release point and the surfacing position. They succeeded in measuring the diameter of the plume vs. depth, but had problems fixing the position of the plume due to problems determining the exact location of the ROV (See 7.1.4).

A number of underwater imaging systems that make use of extremely low light level cameras are available and may have application to this problem. Two technologies are of particular interest. One is the high dynamic range Charged Coupled Device (CCD) camera, similar to the one developed by Roper Scientific Trenton (formerly Princeton Instruments, Inc.) for Woods Hole Oceanographic Institution. The other is the range gated intensified CCD (ICCD).

A CCD camera consists mainly of a silicon chip that collects electrons that are excited into the conduction band. In other words, light from the object being imaged interacts with the silicon thereby releasing electrons that are collected in pixels, and then readout to a computer. When all the pixels are emptied into the computer, the computer displays a digital image of each of the pixels and the amount of light each collected, this produces a grayscale image of the object in the filed of view. Recent use of CCD cameras for deep underwater imaging to depths of 6,000 meters is described in the article by Goldsborough III, et. al., 1998. New hardware and software to extend the imaging capabilities using laser illumination and computer image simulation are described in Jaffe, et.al, 1998. Benefits of CCD technology include the immediate availability of the image; the ability to digitally manipulate, store and display the images; and the ability to apply digital-image processing techniques to enhance specific image features.

The high dynamic range CCD will be adversely affected by the turbulence and turbidity described in Section 7.1.4. There is some chance that by virtue of its higher dynamic range, the desired image information may still be visible through the "virtual fog" of the turbidity. It might require quite sophisticated image processing to recover the desired information from the images. Whether or not this is possible is probably a subject worthy of extended research, and might well vary from case to case (Simpson, 1998).

The gated ICCD with a pulsed illuminator has the advantage of being able to gate out light from in front and behind the object of interest. The camera consists of a CCD imager with an image intensifier (a "night vision" tube, in popular parlance) in front of it. The image intensifier can be used as an extremely fast shutter. Standard models gate at < 2 nanoseconds. A 2 ns gate corresponds to a 1 foot range gate (in air, somewhat shorter in water because the speed of light in water is reduced by the refractive index). So assuming it is feasible to get the camera into a suitable position and keep it steady to within a few inches over the observation, the operator could adjust the range gating by remote control to zoom in on the object of interest while rejecting the light scattered from the turbulence in front of the blowout. (Note: The camera does not need to be within 1 foot of the object being viewed. If the range gate could, for instance, be set for a one foot width from 32 feet to 33 feet. The camera would only accept light reflected from objects between 32 and 33 feet away. Both the range and the width can be electronically adjustable.) Doing this also requires an intense light pulse of typically 1 to 2 ns duration, usually provided by an array of diode lasers. Such illuminators are commercially available but are fairly expensive. This combination is often called LIDAR (light radar). Longer pulses and/or longer gate widths are possible, giving a larger range gate, but less rejection. The gate width can easily be selectable by remote control so the operator could optimize the imaging for the particular situation (Simpson, 1998).

The underwater cameras built by Roper Scientific Trenton have all been developed on a custom basis in cooperation with undersea researchers. The pressure vessels have been provided by the Woods Hole Oceanographic Institution. It is likely they would cooperate in the development of any cameras for blowout application. The cost of the electronics and imaging portion of such a camera could range from $40,00 to over $100,000 for one unit, depending on the requirements.

Another alternative for plume flow characterization to be investigated is the use of a side looking acoustic doppler current profiler.

These applications of these methods to deepwater blowout flow characterization will require further testing and verification.

9.3.2 Oil Properties

Oil properties databases supply the chemical parameters required by three-dimensional trajectory and fate models. The inclusion of oil properties from deepwater wells, and the analysis of the oil properties (i.e. density, viscosity, pour point, water uptake rate, maximum water uptake, and predicted dispersion) both at depth and at the surface, will assist in the selection of the most appropriate countermeasures. Existing crude oil property databases are available from Environment Canada (Environment Canada, 1999) and SINTEF (Daling, 1993). The Environment Canada database was jointly funded by MMS. In Norway, regulations concerning implementation and use of risk analysis in petroleum activities, and the regulations concerning emergency preparedness, are interpreted as requiring the results of oil weathering tests for establishing a credible spill response plan and ensuring the availability of appropriate countermeasures (Lenes, 1999). Response plans must be derived from a proper understanding of oil release behavior in the effected water column to characterize the likely oil disposition.

9.3.3 Detection

The SeaSoar towed sled instrument system and sidescan sonar has been suggested as possible tools for monitoring subsurface oil plumes (Allen, et. al., 1997). Our literature search resulted in one other potential detection candidates, the Sniffer apparatus.

Towed Instrumentation
The SeaSoar, manufactured by Chelsea Instruments, Ltd., is a towed vehicle equipped with impeller-forced wings that can be rotated to allow the vehicle to undulate in the upper ocean. It is capable of undulating from the surface to its maximum operating depth of 500 meters at tow speeds of up to 12 knots following a controlled and adjustable undulating path through the ocean. It is capable of carrying a large suite of sensors. Typically, instrumentation for submerged oil detection would include optical instrumentation such as a flourometer or transmissometer. Product bulletins from Chelsea Instruments Ltd. are included in Appendix C.

Acoustic Systems
Acoustic systems such as fish finders and side scan sonar have both been proposed for submerged oil detection. Side scan sonar systems simultaneously transmit from transducer elements in a towfish two short 100 kHz bursts of sound in two fan-shaped beams oriented at right angles to the survey track line. Reflected signals (usually from the seafloor) are detected by the transducers in the towfish, electronically processed and graphically displayed in a presentation analogous to an oblique angle serial photograph. Ultra high resolution (250kHz and 500 kHz) systems are also available. We could find no records of these systems being used for subsea oil detection though they have been used to locate and map drilling mud releases. Commercial fish finders were used by SINTEF in their underwater tests described in 9.1.2. The ability of sonar to find drifting plumes or globs of oil in the water column has not yet been demonstrated.

Sniffer Systems

The Petroleum and Marine Division of the Australian Geological Survey Organization is using a sniffer apparatus to search for subsurface oil slicks for a variety of petroleum surveys and for hydrocarbon seepage detection within several petroleum hydrocarbon exploration projects (Heggie, 1998). The effective working depth is governed by the winch and cable system and is being extended to 500 meters in 1999. The sniffer detects light-end dissolved hydrocarbon gases in the water column and compares them to relative values that may indicate gas seeps. A description of the system is included in Appendix D (Dutton, 1998).

9.3.4 Surface Oil Surveillance and Monitoring

With the usefulness of fixed wing aircraft and helicopters potentially limited by the remoteness of deepwater sites, space-based imaging systems have the potential to contribute a cost effective method of providing increased surface oil surveillance and monitoring during a blowout. Oil slicks affect water in two important ways that are readily detected by imaging satellites, they increase reflectance in the visible through near-infrared portion of the electromagnetic spectrum, and they smooth the sea surface, reducing the amount of reflected sun glint and radar backscatter. Satellite imagery can be used to provide detailed data on the shape and size of the slick to estimate leakage rates, as is currently done for natural oil seeps. While this may not presently be a viable operational spill response tool, with the planned launch of high resolution, high accuracy commercial satellites, one-meter resolution color enhanced images will soon be available with maximum revisit times of 9 hours for most areas. By the end of 2000, this is expected to drop to a maximum revisit time of four hours for most areas, and this may become a useful tool in the future. This is in addition to the 6 to 30-meter images available now from the Landsat, Spot, Radarsat, Indian and Russia satellites.

The usefulness of space-based images for detecting and tracking oil spills has been demonstrated using Radarsat images of the recent Japan and UK oil spills.

9.4 Recovery of Oil on the Sea Surface

If large amounts of oil reach the surface, it will be necessary to use a variety of countermeasures including dispersants, in-situ burning, mechanical containment and recovery. At the remote open-sea conditions typical of deepwater sites, it is doubtful that mechanical containment and recovery techniques alone will be effective. The availability of sufficient recovered oil storage and/or oil water separators are expected to be limiting items and should receive careful review during the development of deepwater oil spill contingency plans. Likewise, the positioning of response resources to ensure that OPA 90 tier response times can be met must be evaluated. It might be that deepwater platforms would be required to share dedicated pre-positioned response and safety assets as is common in the North Sea.

10.0 Conclusions and Recommendations

10.1 Conclusions

- **Leak Point Probabilities:** A ranking of potential leak points during drilling, completion and workover operations indicates that the probability that a deepwater blowout will occur at the wellhead connector, choke and kill stab (LMRP), through the riser, or outside the casing (a broach) is moderate, while the probability that a blowout would occur from other locations is low. For producing wells, the probability that a blowout would occur at the annulus valve is moderate, while the probability that a blowout would occur from other locations is low.

- **Consequences:** A consequence analysis of leak points indicates that leaks through the drillpipe and broaches are catastrophic and will likely result in a sustained blowout, while leaks from the wellhead connector, through the riser or from the casing seals will have severe consequences. The relative consequence of leaks from other locations is minor.

- **Technical hurdles** to be overcome in order to stop an uncontrolled flow of oil from a deep or ultra deepwater blowout have been developed and explained in detail in Section 7.

  For subsea oil containment the technical hurdles to be overcome during a deepwater blowout include:

  - Predicting the behavior of deepwater currents
  - Ability to manipulate heavy objects on the sea bed
  - Ability to design subsea collectors that are flexible enough to cap a large range of subsea wellhead assemblies and accommodate a high volume of recovered oil, gas and water
  - Ability to approach the blowing well and install containment devices on the seafloor
  - Lack of standardization in subsea wellhead design

  For subsea dispersant application , these include:

  - Availability of equipment and methods for delivering the dispersants to the plume

  For oil remote sensing and tracking, these include:

  - Lack of understanding of plume dynamics
  - Lack of information on oil properties
  - Methods for detecting submerged oil plumes
  - Limited usefulness of surface oil surveillance and monitoring aircraft

  For recovery of oil on the sea surface, technical hurdles include:

  - Logistical problems for mechanical systems dealing with large quantities of recovered oil and water at locations far offshore

- Ability to contain and sustain a safe, controlled burn at remote offshore locations has not been demonstrated

10.2 Recommendations

The following technologies and approaches have merit and deserve the opportunity for additional research and development to determine their ability to address the well control, oil tracking and recovery technical hurdles identified:

- **Deepwater Current Measurement:** Three systems having the potential to measure deepwater currents at the blowout site have been identified: a system using ADCPs deployed at different depths, ALACE and APEX floats. Tests of the usefulness of these systems should be performed and operational methods developed for the deployment and use of the system best suited for use in a deepwater blowout.

- **The Multipurpose Deepwater Crawler (MDC2000)** concept described in Appendix B offers a means to assist with the manipulation of heavy objects, delivery of well control technologies in ultra-deep waters, and for applying dispersants at the wellhead. This blowout countermeasure system can be multifunctional in supporting several different emergency and deepwater operational situations, and preliminary design development should be pursued with this in mind, possibly through a multi-agency design effort.

- **Low Priority for Subsea Collection:** Recovery of oil from a deepwater blowout is unlikely for most subsea releases. The development of subsea collectors and recovery should be given a low priority until the (1) plume modeling methods are refined and demonstrate that significant oil will reach the surface from a deepwater blowout, and (2) wellhead intervention or dispersant application techniques using subsea systems have already been developed and demonstrate the need for additional collection and recovery systems.

- **Subsea Equipment Standardization:** A standardization effort should be undertaken to ensure that all subsea equipment designs incorporate standard methods and equipment for well intervention using standard ROV equipment and tooling.

- **Subsea Dispersant Injection Design:** Methods, dispersant ratios and injection nozzle designs should be developed and tested to determine the most effective design for injection of dispersants directly into a blowout plume. The concept for wellhead independent subsea dispersant application should be further developed.

- **Predicting Deepwater Blowout Plume Dynamics:** The ability to model and predict blowout plume dynamics should be a priority research area, especially the collection of data to validate the predictions.

- **Underwater imaging** systems should be tested and verified on simulated blowouts to determine the best system for this application. The best candidates for testing are the high dynamic range CCD camera, the range gate intensified CCD.

- **Oil properties** from deepwater well samples should be analyzed and made available to NOAA and other organizations for inclusion in three-dimensional and fate models.

- **Subsurface Oil Plume Detection:** Two devices have been identified with the potential to detect subsurface oil plumes: the SeaSoar, and the AGSI Sniffer. Tests of these similar devices should be made during test releases to determine their adequacy for deepwater application, and then the range of the most appropriate system needs to be extended to ultra deepwater. The initial detection tests might be combined with testing of methods to detect submerged orimulsion plumes.

- **Space Based Imaging Systems:** Advances in satellite imaging systems should be monitored as they offer the potential to contribute a cost effective method of providing increased surface oil surveillance and monitoring of remote deepwater sites.

- **Surface Spill Countermeasures:** The availability of sufficient recovered oil storage and/or oil water separators should be a priority item during the development of deepwater spill response plans. Likewise, the positioning of response resources to ensure rapid response must be ensured.

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GLOSSARY

This glossary is a guide for spill planning professionals and other readers who are not familiar with offshore well control operations. Most of the terms are from Holand, 1997 and Mather, 1995.

ANNULAR BOP (BLOWOUT PREVENTER): A device with a generally toroidal shaped steel-reinforced elastomer element that is hydraulically operated to close and seal around any drill pipe size (or other tubular) to provide full closure packing of the wellbore.

ANNULUS: The space surrounding any tubular suspended in the hole. During drilling the circulation fluid flows up the annulus between the drillpipe and the wall of the hole, or, when the well is cased, between the drillpipe and the casing.

BLIND RAM BOP (BLOWOUT PREVENTER): A BOP having rams which seal against each other to close the well bore in the absence of any pipe.

BLOWOUT: A blowout is an uncontrolled flow of formation fluids from a wellbore.

BLOWOUT PREVENTER: A device to control formation pressures in a well by sealing the annulus around the drillpipe (or tubular) when it is suspended in the hole, or alternatively by sealing across the entire hole if no pipe is in it. Blind/Shear Rams have cutting blades that will shear tubulars that may be in the wellbore, while the rams close and seal against the pressure below. Different types of preventers are assembled in a blowout preventer (BOP) stack.

BRIDGE (DOWNHOLE): An obstruction in the hole usually caused by the wall of the hole caving in. This may be caused by formation collapse, which is considered “passive”, or may be induced, which is called “active”.

CASING: Steel pipe set in the hole as drilling progresses to line the hole wall, preventing caving-in and providing a passage to the surface for drilling fluid and for hydrocarbons if the well is proved productive.

CHOKE: A valve like device with a fixed or variable aperture specifically intended to regulate the flow of fluids.

CHRISTMAS TREE: A high pressure assembly of valves, pipes, and fittings installed on a wellhead after completion of drilling to control the flow of oil and gas from the casing.

CONDUCTOR: The first, and largest diameter pipe to be inserted or drilled into the seabed when drilling a well. It keeps the hole open, provides a return passage for the drilling mud and supports the subsequent casing strings.

DIVERTER: A piping arrangement attached to the top of the marine riser that closes the vertical passage and directs the flow of well fluids away from the rig floor and overside.

FLOWLINE: Piping which directs well fluids from the wellbore to the surface equipment.

INFLUX: An unexpected flow of formation fluids into the wellbore.

KICK: See INFLUX

KILL LINE: A high pressure line attached to the BOP stack through which heavy drilling fluid can be pumped into the hole to kill a well. On a semisubmersible or a drill ship the kill line runs down the side of the marine riser.

LOWER MARINE RISER PACKAGE (LMRP): An assembly comprised of the flex or ball joint, an annular blowout preventer, hydraulic accumulators, sections of riser and the riser slip joint, all of which can be detached from the rest of the BOP stack in an emergency to allow the drilling unit to move off location whilst leaving the well secure.

MARINE RISER: The large-diameter pipe connecting the BOP stack to the slip joint of a semisubmersible or drill ship through which the drillstring passes to the well and through which returns of drilling fluid pass from the well to the rig.

MUD: Liquid drilling fluid circulated down the hole and back to the rig.

PACKER: Mechanical or wireline device placed in the hole as a temporary device for sealing one casing string from another, or from the production tubing. Different designs are made for a variety of uses.

PRODUCTION TUBING: Pipe used in wells to conduct fluid from the producing formation into the Christmas tree. Unlike the casing the tubing is designed to be replaced during the life of the well, if required.

ROTARY TABLE: The housing for the mechanism in the center of the drill floor that drives the kelly and turns the drillstring and bit. All downhole tools, casing, etc. are run through its opening.

SLIP JOINT: A telescopic joint inserted near the top of the marine riser to absorb the vertical heaving motion of the drilling unit when in a seaway.

SURFACE CONTROLLED SUBSURFACE SAFETY VALVE (SCSSV): A SCSSV is located in the production tubing subsurface. The valve can be used for closing in a well if a topside situation occurs that disables the Christmas tree valves. The valve is controlled from the surface. These valves are frequently referred to as DHSVs (Down Hole Safety Valves). A DHSV does, however, not have to be surfaced controlled; it can be flow controlled. The flow controlled valves are frequently referred to as storm chokes.

TRIPPING: The operation of pulling the drillstring out of the well or running the drillstring into the well.

WELL COMPLETION: The final phase of operations after total depth has been reached (e.g., when the well is fitted with production equipment).

WELLHEAD: Permanent equipment used to secure and seal the casing strings and production tubing and to provide a mounting place for the Christmas trees.

WORKOVER: An operation in which a rig is employed to restore or improve production from a completed well.

Appendix A – Data Sheets for ALACE and APEX Floats

Appendix B - The Multipurpose Deepwater Crawler (MDC 2000)

Concept Design

B.1 Introduction

The Multipurpose Deepwater Crawler (MDC) concept evolved as a potential solution to the technical hurdles identified in Section 7, i.e. the deepwater currents, ability to manipulate heavy objects, provide subsea power, ability to approach the blowout plume, and provide wellhead intervention or inject dispersants into the plume.

B.2 Background

Based upon the technical hurdles identified in Section 7.0 of the report, and knowledge of ROV technology, the team identified a number of critical design points for the MDC concept.

- A major reason that none of the earlier blowout response concepts have been developed is the high capital cost for equipment dedicated solely for an operation that has a small probability of occurrence. This means that the equipment should not be dedicated only for deep water blow out operations. It should also be able to perform other subsea or land based tasks. This is important when considering life time costs. The MDC should be multipurpose.

- The MDC should be able to perform oil well blowout intervention tasks as follows:

  Monitor and evaluate the situation around the oil well
  Cut debris
  Connect wires for heavy surface assisted lifts
  Cut and cap pipes for access to the kill and choke lines
  Attach well killing fluid lines
  Provide hydraulic power as a backup for BOP control systems
  Inject dispersant.

B.3 General Description

The MDC concept that is not a free swimming unit. It operates from the sea bed and uses the sea floor as an operational platform. The vehicle itself is equipped with tractor belts and moves as a conventional tractor. The vehicle will act as a platform for a hydraulic arm with a reach of 40 to 45 ft and several six degree-of-freedom manipulators. During operation of the arm the vehicle will secure itself to the seafloor by hydraulic operated screw piles. The unit is powered and controlled from a subsea platform which is installed by a crane vessel in a conventional way. All critical components such as electro hydraulic powerpack, junction boxes and control system are fixed to the platform. The vehicle gets hydraulic supply from the platform through an umbilical containing hydraulic lines as well as signal lines for operating solenoid valves and transferring data from the onboard surveillance system. The long reach hydraulic arm can be equipped with all available ROV tools such as cutters, saws, grinders etc. In addition the arms will be able to carry a tool for dispersant injection into the jet zone of the blowout plume.

The MDC should also be able to operate on land. This means that the vehicle is build for ultra deep water but is powerful enough to operate on land. During subsea operation, additional weight is added to the vehicle. Since the vehicle itself is intrinsically safe it will be able to operate in hazardous areas on land such as in mines, ship tanks, etc.

B.4 Equipment Description

The MDC would be comprised of three main elements as shown in Figure B-1 and described in the following sections:

- base template,
- control platform
- vehicle

B.4.1 Base Template

The main function of the base template will be to provide a structural support base for the control platform and lock it to the sea floor. It is equipped with four hydraulic operated screw piles and is lowered to the sea floor by proven methods. During installation to the sea floor, guide wires will be established to the surface. The guide wires will guide the control platform onto guide posts located on the base template.

B.4.2 Control Platform

The control platform is a separate unit containing the MDC, a hydraulic operated umbilical drum, pressure vessel with the control system, pressure vessel with the transformer and junction box, and the electro hydraulic power pack. Electric power has to be supplied from the surface. Due to the long distance, a high voltage system should be used. Vehicle, manipulator and optical equipment control should occur via fiber optics in order to prevent signal interference from the high voltage system.

The control system will have to operate at surface pressure and will need to be located inside a pressure vessel with sub sea connectors rated for ultra deep water. This system is similar to those used on ROVs designed for ultra deep water.

The hydraulic system will be pressure balanced and will work independent of the water depth. However, special emphasis must be put on the design in order to avoid air or gas bubbles in the system.

B.4.3 Multipurpose Deepwater Crawler Vehicle

The MDC vehicle will be of a conventional type as presently used for subsea pipeline and cable trenching. It is hydraulic operated and the power is taken from the electro hydraulic power pack on the control platform. The power is supplied via an umbilical (See Figure B-2) from the hydraulic operated umbilical drum. The controls onboard the crawler should be of a conventional type and all functions are initiated from the control system in the pressure vessel located on the control platform.

The hydraulic operated combined crane and manipulator arm will have to be specially designed for the vehicle. It needs to have a long reach and at the same time it needs to fold back in order to be accommodated on the MDC and the control platform. A second, shorter manipulator arm is desirable to assist with positioning of imaging systems (as described in Section 9.3.1 of the report) or other tools. Weight will be added to the unit in order for it to be stable on the sea floor in heavy current. The tractor drive will be of the same type as that used on land based mini-tractors. It should be sturdy, powerful and hydraulic operated.

During operation of the long manipulator arm, the MDC will have to be supported by hydraulic operated telescopic support pods. The unit should also be equipped with screw type piles in order to lock itself to the seabed during operation in unconsolidated sediments.

B.5 Equipment Operation

Deepwater and ultra deepwater blowouts are expected to be rare. Therefore, the MDC has been designed to be multifunctional and capable for use on a number of tasks including operation in deep and ultra deep waters to deliver blowout countermeasures, use in shallower depths to perform routine subsea operations, surf zone delivery of offload hoses, and surface operations involving hazardous materials.

B.5.1 Blowout Countermeasure Operations In Deep and Ultra Deep Waters

The MDC is designed for operation in water depths beyond 6500 ft. and all proposed procedures are based upon proven methods.

Installation

The base template can be installed from the surface by a dynamically positioned crane vessel. The template is lowered to the seabed and is equipped with transponders and/or an inertia navigational system (noise from the blowing well may disturb the transponder signal).
During launch, the guide wire connection is established to the surface.

The control platform containing the MDC is lowered onto the template via these guide wires. By having a fixed template on the seabed the control platform can be retrieved at any time for service or repair while maintaining connection to the seafloor near the blowout.

The control platform will enter the guideposts on the template and lock itself to the template.
A landing ramp will be lowered and the MDC can leave the control platform.

See Figures B-3.1 and B-3.2.

Operation

The MDC will be dependant upon a reliable navigational system as well as a system for orientation in a dark, possibly sediment filled environment. It is expected that the poor visibility will be one of the most challenging parts in the design of the MDC. The vehicle is operated from the surface, where all controls are located. Both vehicle movements and arm manipulation will be carried out by a pilot onboard the surface vessel.

The first objective for the MDC, once in place, is to supply information to the surface about: current velocity and direction, conditions around the blowing well, and to obtain an image of the blowing well.

Depending upon the operation, the MDC will be able to retrieve tools from a cassette located on the vehicle. The cassette tool system will need to be developed as part of the next (feasibility) design effort and should consider the other operations outlined in Section B.5.2.

If dispersant application is required, dispersant will have to be supplied from the surface via a separate hose to the control platform or to the MDC itself. Alternative methods have to be evaluated depending upon the amount of dispersant needed. The MDC will be equipped with high pressure spray nozzles in the end of the manipulator arm. It might also be possible, depending upon the situation, for the MDC to make a hose connection to the kill and choke line for direct injection of dispersant to the oil well.

See the concept for subsea blowout countermeasure operations in Figure B-4.

B.5.2 Other Subsea Operations

The MDC is a multipurpose tool which can be used in a number of subsea applications. If the MDC is operated in water depths above approximately 300 feet, the base template and control platforms as previously described, may not be needed. Hydraulic power could then be supplied directly from the surface.

Subsea Clean-up Operations

The MDC can be used for subsea removal of hazardous materials like PCBs, chemicals and sunken oil located on the sea floor. The unit can then be equipped with a dredge suction head combined with a rotating seabed cutter attached to the manipulator arm. Suction can be taken from any system that creates underpressure, but one solution is to take the suction from a water pump driven ejector system located either on the seafloor, onboard an operating vessel or on the control platform. See Figure B-5.

Subsea Inspection

The MDC should also be useful for inspection and repair operations on subsea pipes and cables. Since the unit is fixed to the seabed, thrusters, as used on conventional ROVs, will not stir up the sediments and thus limit the visibility. See Figure B-6.

Subsea Cable Laying

The MDC will be able to perform cable laying operations. The unit can be equipped with a trailer containing pumps and a water jet sword used for cutting into the seabed. The arm of the MDC could be used to guide the cable between the tractor belts and into the cable laying trailer. See figure B-7. Such systems have been used in Scandinavia.

B.5.3 Surf Zone Operation

The MDC would have been a useful tool for the recent container ship groundings and associated oil spills that occurred offshore Alaska (M/V Kuroshima) and Oregon (M/V New Carissa). The MDC could have been used to efficiently deliver the floating hose offload system to the stranded tankers by drving the hose into the surf and lifting it up to the tanker using the long manipulator arm.

B.5.4 Surface Operation

The MDC could be designed for surface operation as well as subsea operation. This would make the system truly multipurpose. The design itself will give the MDC some unique features as a land operated robot, as the subsurface design will be intrinsically safe. No electric components are used in the power system and the solenoid valves for operation of the hydraulic system will be installed inside a pressure balanced oil reservoir. A separate control system will be used for the surface operation. The template and the control platform are not needed for such operation. During land based operation the MDC will be lighter than operated subsea, extra weight is only added to the unit in a subsurface mode.

Operation in Enclosed Gas Dangerous Areas

The MDC with its long reach manipulator arm will be a possible asset for working in enclosed areas where there is a danger of explosion. It can basically perform the same functions as in the subsurface mode. Power can be taken directly from a diesel hydraulic power pack located outside the gas zone. See Figure B-8.

Mine Hunting and Mine Demolition

The long reach arm can be equipped with mine detection devices and the tractor belts will ensure that the vehicle will be able to move in the terrain. The reach for the mine detection equipment will have a radius of 45ft. By equipping the arm with a steel rotating drum the unit may be used to set off possible mines. See Figure B-9.

Investigation and Removal of Hazardous Material

The MDC will with its long reach arm be ideal for investigation of hazardous material as well as removal of such material. See Figure B-10.

B.6 Costs

System equipment and operational costs will be determined during the follow-on preliminary design phase. We estimate design costs to be on the order of $500,000 and vehicle construction costs to be on the order of $2,500,000.

Appendix C - Product Bulletins from Chelsea Instruments Ltd.

Product Bulletin

SeaSoar Mark II

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September 1997

1 INTRODUCTION

1.1 General

The SeaSoar oceanographic vehicle is a large volume instrument carrier which can be towed from a surface ship at controllable depths. It is built by Chelsea Instruments Limited (CI Ltd.), under licence from the Natural Environment Research Council (Southampton Oceanography Centre), UK. It is capable of carrying a large suite of sensors, at speeds of up to 12 knots to depths of 500m, following a controlled and adjustable undulating path through the sea.

SeaSoar forms part of a dynamic system where the actual depth and path pattern, obtained in practice, is dependant upon many factors. i.e. Instrumentation load, ship speed, cable tension and required YO-YO parameters. Any new system should undergo sea trials and the performance logged, to determine the optimum controller settings needed to meet the required performance.

Sampled data, obtained from sensors mounted in SeaSoar, are transmitted to the towing vessel for processing, display and storage via a multicore tow cable. A typical configuration is shown in Figure 1. The basic system comprises:

- **The SeaSoar Underwater Vehicle:** This may be supplied with an unmounted pressure (depth) sensor.

- **The SeaSoar Deck Control Unit:** The ship board Deck Unit is used to control the pitch of the wings thus enabling the vehicle to dive or climb as required. Operator control is via the PC based SeaFlight Software package.

Power supply to the package can be either 110V or 220V AC, 50 or 60Hz, this must be specified by the customer at time of order. Mains supply to the Deck Units must provide an EARTH terminal.

- **Training:** Chelsea Instruments Ltd. will also supply two days of 'at sea' training. Experience has shown that this is very cost effective when taking into account the avoidance of set-backs, delays and possible damage.

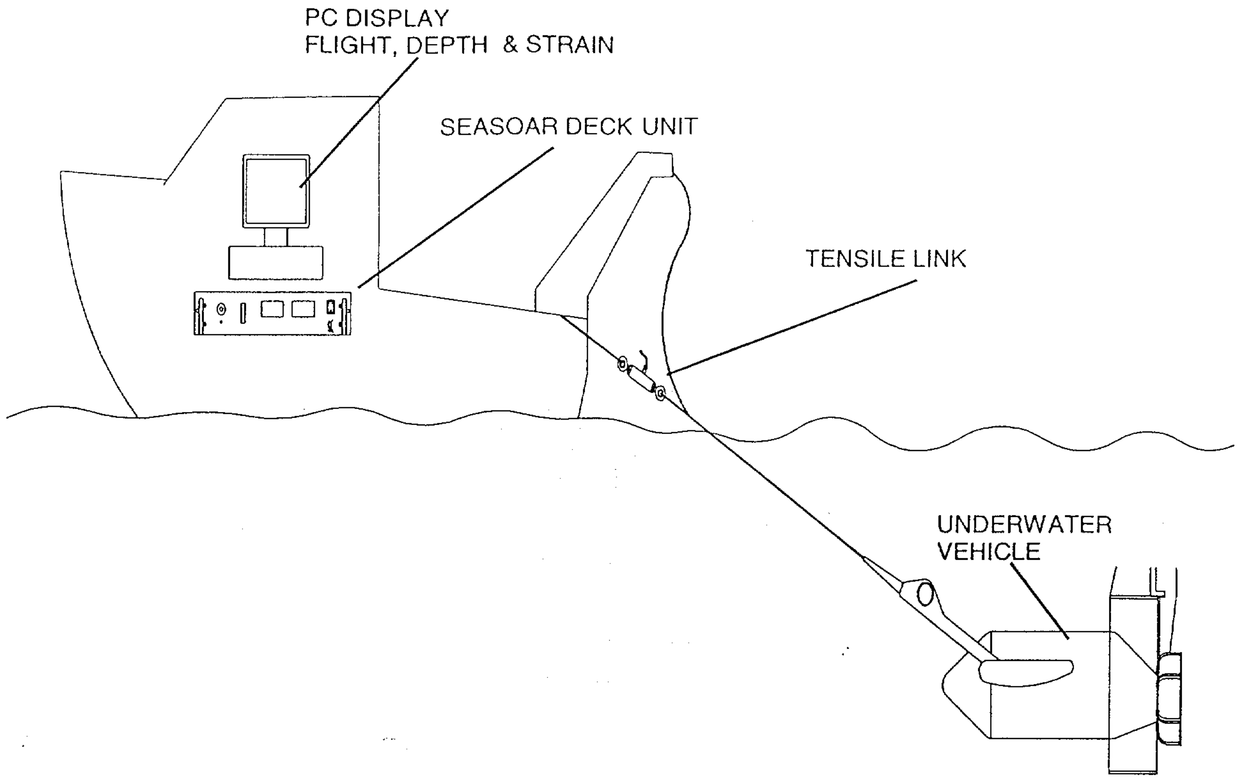

Fig.No. 1 **Standard Configuration**

1.2 Options

The SeaSoar system has been designed as a very flexible package. The Standard Package can be purchased as a basic towing unit or together with a range of options.

CI Ltd. can supply an extensive range of underwater monitoring instruments, including sensors for CTD, pH, Redox, Dissolved Oxygen, Turbidity, Transmission and Fluorescence.

Specific options relating to the SeaSoar System that can be supplied include:

- A suitable winch, cable, cable fairing and associated equipment to suit the varying applications of the SeaSoar System.
- The design and production of a suitable underwater cable harness for connection of the SeaSoar hydraulic unit and any sensors carried, to the tow cable.
- The design and supply of suitable mounting arrangements for varying instrumentation payloads, together with a single or double push-rod assembly for the hydraulic unit to allow a wider variety of mounting arrangements within the vehicle.

- Deck Transportation Cradle. A welded steel deck cradle, painted for use in a marine environment, is provided for stowage of the SeaSoar vehicle when on the deck of the operating vessel. This cradle additionally aids transportation of the SeaSoar system between laboratory and ship or into storage. The cradle comes supplied with casters for ease of mobility and is also supplied with brackets which can be welded to the deck of the operating vessel to secure the cradle for stowage at sea.

- Tensile link (either separate or integral to the winch system) to give a real time readout of cable tension.

- Engineering package for SeaSoar to give a real time display of vehicle pitch, roll and yaw.

- Basic operational spares kit for the Vehicle, Hydraulic Unit and a SeaSoar tool kit.

- A Servo Valve / Wing Movement Test Box and interface cable is available allowing a test signal (current) to be sent to the electro-hydraulic servo valve (Moog) within the SeaSoar hydraulic unit, and thus initiating wing movement when the impeller is turned by hand.

1.3 Principle of Operation

The SeaSoar is an undulating towed vehicle capable of deploying a large oceanographic payload to depths of up to 500m, depending upon tow cable configuration. Power is supplied to the wing actuating ram by a water driven impeller connected to the hydraulic pump within the SeaSoar hydraulic unit. The system utilises a digital servo loop in which the wing angle of the vehicle is controlled by the difference between the observed pressure and a synthesised command signal. Based on this difference, the SeaSoar deck unit generates a current signal that proportionally controls a servo valve within the hydraulic unit to either extend or retract the hydraulic ram. The ram is coupled to the wings rotating them through varying pitch angles to enable SeaSoar to climb or dive through the water column.

It is recommended that SeaSoar be towed on Rochester 7-H-314 AXX 8.2mm diameter, double armoured, 7 conductor cable or a close equivalent. With an unfaired tow cable SeaSoar will reach depths in excess of 150m. With low drag Indal fairing fitted to the outboard end of the tow cable much greater depths can be achieved. A 650m cable with the outboard 500m faired gives SeaSoar a maximum depth capability of 350 - 400m, whilst a 1000m tow cable with the outboard 750m faired enables SeaSoar to reach the desired depths of 450 - 500m.

2 SPECIFICATIONS

2.1 SeaSoar Body

Length (excluding bridle)	1.5m
Height (rudder bar down)	0.98m
Width over wing hooks	1.60m
Weight, in air (inc. hydraulic unit excluding Sensors)	150kg

2.2 Recommended Tow Cable

Type		Rochester 7-H-314AXX (High strength armour)
Diameter		8.2mm
Conductors		7
Breaking strain		51.6 kN
Working load		20.0 kN
Bend diameter (min.)		43 cm
Weight:	Air	268 kg/km
	Freshwater	220 kg/km

2.3 Recommended Fairing

Type	Indal Technologies Flexnose FA-478-350-1
Section length	10.2 cm
Sheave diameter	91 cm (minimum)

2.4 Typical Performance

With cable (1000m)	Flexnose fairing	Unfaired
Maximum depth	500m	100m
Maximum tow speed	12 knots	10 knots
Minimum operating speed	5 knots	4.5knots
Maximum rate of change of depth	1m/sec	4.5m/sec
Level towing accuracy	+/- 3m	+/- 1m

2.5 Typical Winch

With cable	*Faired	Unfaired
Drum diameter (minimum)	1.75m*	0.45m
Drum capacity	750-1000m*	250m
Maximum pull	400kg	300kg
Maximum line speed	1m/sec	1m/sec
Minimum line speed	5m/min	5m/min

* Dependent upon the type of fairing and cable length employed.

3 VEHICLE CONSTRUCTION

The Underwater Vehicle, illustrated in Figure 2, consists of the following main sections:

- **Towing Bridle**

The bridle applies the tow cable forces to the wing drive shaft. Being made from stainless steel, it is a very stiff structure, designed to cope with the weight of the vehicle body and hard driving of the system.

- **Two Wings with Hook Rails**

The wings are moulded from glass reinforced polyester, they are very strong with 50mm dia. stainless steel pivots which are connected together by a drive shaft . The drive shaft is coupled to the hydraulic ram via a short crank which converts ram motion to wing rotation. Both single and double push rod options are available, unless specified by the customer a single push rod is supplied as standard. Hook Rails assist in the recovery procedure.

- **Main Body**

The central body is rectangular with a stainless steel, deep-sided frame, this provides maximum volume for instrument carrying and strength. Quick release stainless steel panels, top and bottom, allow maximum accessibility without the use of tools. The central section is bolted to streamlined GRP nose and tail sections. The use of stainless steel and GRP minimises corrosion and enhances the durability of SeaSoar.

The stability of the vehicle is enhanced by hanging a streamlined weight below the front of the body. This, together with the streamlined nose and high profile tail section, adds to the towing stability of the vehicle. The streamlined weight may not be required when large instrument loads are carried.

- **Tail**

The tail surfaces consist of two flat, horizontal reinforced polypropylene plates mounted on and connected to, the main body by a similar vertically positioned plate. One horizontal plate is located well above the top of the vehicle body, the other well below.

- **Rudder Plate and Balance**

A stainless-steel rudder plate and balance arm is fitted to the rear of the tail section as a stabiliser. It is freely hinged to the tail by means of pintles. When the vehicle rolls to one side, the effect of gravity on the balance arm turns the rudder in the same direction. The resulting hydrodynamic force acts to return the vehicle to vertical as well as correcting yaw.

3 VEHICLE CONSTRUCTION (continued)

- **Impellor with Ring Guard**

The Impellor is mounted at the rear of the main body beneath the rudder. It is used to drive a hydraulic gear pump which generates power for the hydraulic ram which, in turn, pivots the wings. Constructed from stainless steel, the impellor has six blades and is 280mm in diameter. A guard ring is fitted to protect the impellor from damage during operation and deployment.

- **Hydraulic Unit (Mark II)**

A new Mark II hydraulic unit has been developed to meet the need of prolonged deployments at sea with minimal maintenance requirements. After an extensive programme of laboratory and at-sea trials this is now fitted as standard to all SeaSoars.

The Hydraulic Unit is located within the Main Body of SeaSoar. As the vehicle is pulled through the water, the impellor drives an axial piston pump which generates hydraulic pressure. This pressure is fed to the servo valve which controls the flow of oil to the double acting piston in response to a control signal supplied from the SeaSoar Controller via the tow cable. Movement of the piston alters the angle of the wings by means of a push rod arrangement acting on the wing crankshaft.

Note: Single or Double Push Rod options are available, this must be specified at time of order.

The unit does not incorporate an internally mounted pressure transducer; depth feed-back for vehicle control from the surface is supplied by either the existing CIL pressure transducer mounted in a separate pressure housing assembly, or depth sensors available on auxiliary 'payload' instrumentation.

The unit incorporates supply and return line filters to maintain the correct ISO oil cleanliness code during operation, includes an adjustable pressure relief-valve to set the maximum wing-shaft 'stalling' torque.

To ensure that the actuating force is the same in each direction of travel and to maintain a fixed volume servo-circuit, the double-acting piston is pressure balanced via an additional internal sea water port. Minor variations in volume with piston travel and the larger volume changes as a result of the coefficient of thermal expansion of the oil over the storage temperature range of the unit, are allowed for by using an internally mounted compensator piston.

The new Mark II hydraulic unit is electrically compatible with the existing Mark I unit. It is readily installed into existing SeaSoars using an adaptor kit and will not intrude into any additional internal payload areas. The centre of gravity of the SeaSoar is not significantly affected.

Each new Mark II hydraulic unit is issued with a performance certificate showing the input and output powers achieved.

Fig. No. 2 The Underwater Vehicle

4 DECK UNITS

The original SeaSoar Deck Controller has now been replaced by a PC based system using technology licensed from the Woods Hole Oceanographic Institute (WHOI). This enables the user to have real time computer control over the SeaSoar's flight profile together with the storage and display of the flight parameters.

The SeaSoar Controller consists of a small deck unit, which under PC control, generates the error current which is passed down the tow cable to the electro-hydraulic servo valve within the SeaSoar hydraulic power unit. This valve error current controls the extension or retraction of the hydraulic ram which in turn sets the SeaSoar wings into the dive or climb attitude. (Figure 3).

Fig.No. 3

Minimum Computer Specification:

- 100 MHz Pentium processor (or equivalent)
- 8 Mbyte RAM
- 3.5" floppy disc drive
- 500 Mbyte hard disc
- 14" colour SVGA monitor
- DOS 6.22

The SeaFlight BASIC programme, running on the SeaSoar Control PC generates a saw-tooth command pattern which represents an ideal trajectory for the SeaSoar. The shape and DC level of the command curve is set via software. The difference between the command signal and pressure measured inside the SeaSoar vehicle (taken either from an installed CTD system, or a separate pressure transducer) is the loop following error signal. This error signal is passed to the SeaSoar Deck Unit, via the PC printer port, where it is converted into the corresponding current signal. This current, called the valve current, is sent down the tow cable to set the electro-hydraulic valve in the hydraulic unit to either extend or retract the hydraulic unit's piston. The hydraulic piston in turn moves the SeaSoar wings into wing-up or wing-down positions at a rate proportional to the valve current. A feedback loop is thus formed, in which the pitch of the SeaSoar wings is continually adjusted as the vehicle attempts to alter its depth until the output of the pressure transducer matches the command signal.

AN ADC card fitted to the SeaSoar Control PC enables the signal from the tow cable load cell (if fitted) to display and log the cable tension.

The SeaSoar deck unit (heavy line in Figure 3) is configured in a 19" 2U high mains powered case, with a front panel mounted analogue edge meter displaying the valve current. The meter needle provides an indication of SeaSoar's attitude with up / down orientations corresponding to SeaSoar climbing and diving respectively. The actual valve current sent down the tow cable is also displayed digitally on the front panel and monitored by the SeaSoar Control PC. The current generator design is such that the valve current passed to the SeaSoar hydraulic unit is independent of the load presented by the tow cable/electro-hydraulic valve. Additionally, a front panel switch allows the user to over-ride the SeaSoar flight programme, permitting manual control of the vehicle wing angle via a front panel potentiometer. In the event of a computer malfunction this facility allows SeaSoar to be brought to the surface and recovered in a controlled manner.

5. SOFTWARE

• SeaSoar Flight Control Software “SeaFlight”

The SeaFlight control software enables the user to programme SeaSoar's undulation profile and the system servo parameters. The software provides for user control of the following parameters.

1. P_{min} - minimum depth
2. P_{max} - maximum depth
3. Period - period of undulation
4. g_0 - 1st programmable gain
5. g_1 - 2nd programmable gain
6. P_{up} - Wing will not turn “up” before P_{up}
7. P_{down} - Wing will not turn “down” before P_{down}
8. Bias - Bias to valve current

Visually SeaFlight displays the following parameters and logs them to the PC hard disk should future analysis be necessary.

1. Command Voltage
2. Pressure (CTD)
3. Error Current (to electro-hydraulic valve)
4. Cable Tension (at the deck)

The PC page up / page down keys give the user direct control over SeaSoar's wing angle, over-riding the computer flight programme, permitting manual adjustment of the vehicles climb or dive through the water column. Thus, in an emergency (say in shallow waters) the use can rapidly command SeaSoar to climb to the surface at a keystroke (page up). Additional manual intervention allows the user to advance or retard the command voltage bringing the command signal and SeaSoar's actual flight profile back into phase should they start to diverge. After manual intervention SeaSoar can be put back under computer control via the keyboard.

6 WINCH AND CABLE SYSTEM

SeaSoar requires a dedicated winch and cable system, this may be a fixed installation or a mobile system. The users individual requirements dictates the type of winch used. The operational depth will dictate whether the tow cable is faired or un-faired; this will influence the type of winch required, using un-faired, a multilayer drum will suffice. The use of fairing necessitates a single layer winch and hence a larger winch barrel.

Note: The winch is only used to deploy and recover SeaSoar; during towing the cable MUST be stropped to a firm fixing point on the ship structure.

Chelsea Instruments do not manufacture oceanographic winches. We have built a strong liaison with several approved suppliers who can provide electric, hydraulic and diesel hydraulic winches specifically designed for use with SeaSoar.

• Typical Winch (Unfaired Cable)

Designed to handle up to 250m of un-faired cable, typically powered by a 5kW electro hydraulic drive and has single lever bi-directional speed control. Line speeds are variable between zero and 1 m/sec with a max. line pull of 300kg. Reeving gear allows the cable to be spooled neatly onto the drum. A slip-ring unit allows continuous control of SeaSoar while launching or recovering. A small hydraulically held off, disc brake will hold the cable at up to 300kg loads but is not designed to sustain full towing loads. A plain cable of typically 250m in length will allow a maximum depth of about 100m to be attained. Longer cable lengths are possible but it is necessary to determine this during sea trials, where vehicle performance and cable strain are closely monitored.

• Typical Winch (Faired Cable)

To attain the full performance of SeaSoar it is recommended that 1000 metres of Rochester cable (7-H-314AXX) is used, of which 750 metres is faired using the Indal Technologies FA-478-350-1 Flexnose Fairing. At a speed of 10 knots, an undulation range from the surface to 500 metres may be achieved.

This configuration will require a dedicated winch and towing sheave system. The faired tow cable can only be reeled onto a single layer winch drum to avoid damage to the fairing. The final pulley sheave (suspended from the towing vessels' A-Frame) must be of sufficient bend diameter (91 cm minimum) but also have an appropriate lead in device to orientate the free-hanging fairing.

- **Lifting Equipment**

In order to launch and recover the vehicle, it is necessary to have a means of lifting it over the stern, preferably an 'A' frame. The tow cable is led over the launching sheave attached to the 'A' frame in such a manner that the cable may be transferred to the towing sheave on completion of the launch. The 'A' frame should extend at least as far behind the vessel as the deck is above the water level. If an 'A' frame is not available an articulated crane may be used. This can cause complication in the launch and recovery processes, as the SeaSoar winch and crane operators have to work in unison. The crane should have a lifting capacity of not less than 400kg at a reach well clear of the ships stern. The wing hook rails can be used to steady the vehicle during launch and recovery.

- **Tow Cable Strain Gauge**

A five tonne strain gauge (Strainstall load cell type 1849) is available for fitting to the deck end of the tow cable, enabling the SeaSoar towing loads to be monitored during deployment. The strain gauge is powered via a four core screened deck cable running from the SeaSoar Deck Unit to the winch. A 50m strain gauge deck cable is provided, through which the strain gauge output is also routed back to its conditioning amplifier in the SeaSoar Deck Unit. The cable tension is displayed and logged with the other SeaSoar flight parameters on the SeaSoar Control PC.

Once SeaSoar is deployed the strain gauge is attached to the tow cable and anchored to a deck strong point, this arrangement additionally serving to remove the towing loads (up to 1400 Kg) from the winch during extended tows. Load transfer is achieved by taking the towing strains through the strop arrangement (Figure 4)

The load transfer arrangement requires the supply of the following items, all of which will be supplied proof tested to 3 tonne.

Strop 1	Deck strong point to strain link strop constructed from 11mm galvanised wire 2 metres long, terminated each end with a thimble.
Strop 2	Strain link to cable puller strop constructed from 11mm galvanised wire 3m long, with a thimble each end and a swivel in the middle.
Cable Puller*	For transferring the towing loads from an unfaired section of the 7-H-314AXX tow cable to the strop arrangement.
4 off shackle	For terminating the loose ends of the two strops.

Several winch manufacturers incorporate the strain gauge within the winch drum. This offers a very simple solution and negates the need for separate strops and cable pullers. This may be specified as part of the overall SeaSoar system

Fig.No. 4

- **SeaSoar Underwater Body Deck and Transportation Cradle**

A welded steel deck cradle, painted for use in a marine environment, is provided for stowage of the SeaSoar vehicle when on the deck of the operating vessel. This cradle additionally aids transportation of the SeaSoar system between laboratory and ship or into storage. The cradle comes supplied with casters for ease of mobility and is also supplied with brackets which can be welded to the deck of the operating vessel to secure the cradle for stowage at sea.

Chelsea Instruments has two other towed oceanographic vehicles in its fleet. If you would like Product Bulletins on either of these please contact the Marketing Department.

Product Bulletin

Aquapack
CTDF

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November 1996

1 OVERVIEW

Aquapack CTDF is a robust conductivity, temperature, depth and fluorimeter measuring system. It is also a real time data logging and transmission system, monitoring the integral CTDF sensors and any auxiliary instruments. Variants of the fluorimeter are available for the determination of Chlorophyll A, Rhodamine-B, fluoroscein or turbidity (nephelometry). Each application uses a common pulsed light source but requires a unique set of light filters in both the emission and detection paths. The configuration is factory set by the selection of optical filters and spacers. Special builds are available that allow the monitoring of a larger suite of Chelsea Instrument sensors or those of other manufactures.

Aquapack may be mounted on a towed vehicle such as Chelsea Instruments' Aquashuttle, Nv-Shuttle or Seasoar, it can also be deployed on buoys, on a mooring, or vertically in a profiling mode. It can be deployed to depths of 200 metres from dedicated oceanographic research vessels or ships of opportunity.

It is used with either the Chelsea Instruments' Standard or Portable Interface Unit that acts as an RS232 interface to the customers' PC Terminal, and houses a power supply for both the Aquapack CTDF and any auxiliary instruments.

2 SPECIFICATION

• Size:		170mm dia. X 310mm
• Weight:		11Kg in air 6Kg in water
• Depth Rating:		200m
• Housing Material:		Titanium
• External Input:	Standard Interface Unit Portable Interface Unit	18-72 VDC 10-15 VDC
• Logger Capacity		2Mbyte (expandable to 8Mbyte)
• Number of readings		50K of all channels
• Number of channels		16 (32 channel special variant is available)
• Interface Type		RS422
• Data rate		Up to 38.4K baud
• Scanning rate		50Hz to 1 sample/day

Sensors	**Type**	**Range**	**Accuracy**	**Resolution**
Temperature:	Pt resistance	-2 to +35^{O}C	0.003^{O}C	0.0005^{O}C
Conductivity:	Induction Cell	1-70mmho/cm	0.005mmho/cm	0.001mmho/cm
Pressure:	Strain Gauge with temp. compensation	0-200 dbar	0.2 dbar	0.003 dbar
Fluorescence:	Fluorimeter	0.01-100ug/l	0.02ug/l*	0.005ug/l*

* or ± 3% of the reading whichever is greater

3 TECHNICAL DESCRIPTION

- **The Deck Unit**

The **Standard Interface** is a mains powered (110 - 240 VAC input) unit which converts the RS422 communications protocol of our subsea sensors / instrumentation (needed for communications over long cables) to RS232 for interfacing to a host PC / notebook computer running Aquasoft.

Having a 72 VDC output it is specifically designed with sufficient voltage overhead to operate on most multicore oceanographic cables up to 1000 metres long when providing 1A to the subsea instrumentation.

The standard interface unit is typically used in real time deployments of SeaSoar and Aquashuttle based systems and profiling packages. However it can also be used in the laboratory during sensor calibrations etc.

The **Portable Interface Unit** converts the RS422 communications protocol of the subsea instruments to RS232 for interfacing to a host PC running Aquasoft. It has been designed to enable configuration of the subsea instrumentation prior to deployment, data extraction after deployment and laboratory applications using short, low resistance cables (5 - 10 metres).

Having a low voltage output (16 VDC) the interface unit is not designed to withstand large voltage drops experienced when deploying instruments on long cables. It is intended to provide the user with the ability to set the sensor logging configurations and extract data.

A mains powered adapter (110 - 240 VAC) allows recharging of the internal battery whist simultaneously powering the instrument (which for example may be undergoing re calibration).

This unit is not designed to provide power <u>during</u> deployment.

- **The PC Terminal** (not supplied by CI)

The PC Terminal must meet the following requirements:

- IBM PC or compatible computer, PCDOS/MSDOS 3.0 or higher
- 256K RAM minimum, - RS232 port (COM1: or COM2:)
- Monochrome display adaptor (text display of depth only)
  or EGA/VGA display adaptor (graphical display of depth)

- **Aquapack Logger**

Aquapack is the centre of intelligence for all communication between the surface, its own CTDF instrumentation and any ancillary instruments. A titanium housing contains the sensors, a processing board and a data transmission/logger circuit board. Data is either stored or transmitted direct to the surface via the RS422 interface.

The logger circuit board houses a 2Mbyte memory, 16 channel data logger and RS 422 communications interface. (Default: 9600 baud, 8 bits, no parity, one stop bit)

The data logger has two modes of operation, Machine Mode and Verbose Mode.

1. Machine Mode is used for simple communication with an intelligent top-end software system
2. Verbose Mode is used when communication is via a dumb terminal and full prompts and messages are available.

- **Aquapack CTD**

1. Conductivity is measured using an inductive cell which uses magnetic coupling to monitor current through the water as a measure of conductivity. It consists of two iron transformer toroids cast in epoxy resin so there are no electrodes that can be contaminated. The large hole diameter allows easy cleaning and only fractional changes in cross-section when occasional particles wash through.
2. The temperature sensor projects into the water and is protected by a perforated sleeve. The sensor is a platinum resistance thermometer placed in one arm of an automatic null balancing bridge circuit. The temperature and conductivity sensors have a matched time response to prevent 'glitches' in the salinity calculations.
3. The pressure transducer is mounted on the inside of the pressure vessel so that the sensing diaphragm is in contact with the water sample.

- **Aquapack Fluorimeter**

The fluorimeter uses a pulsed light technique because this allows for discrimination against variations in ambient light signals. Since the pulse lasts for only approximately two microseconds the high speed signal processing circuits consider the ambient light intensity as 'steady'. The optical layout is shown in Fig.No.1

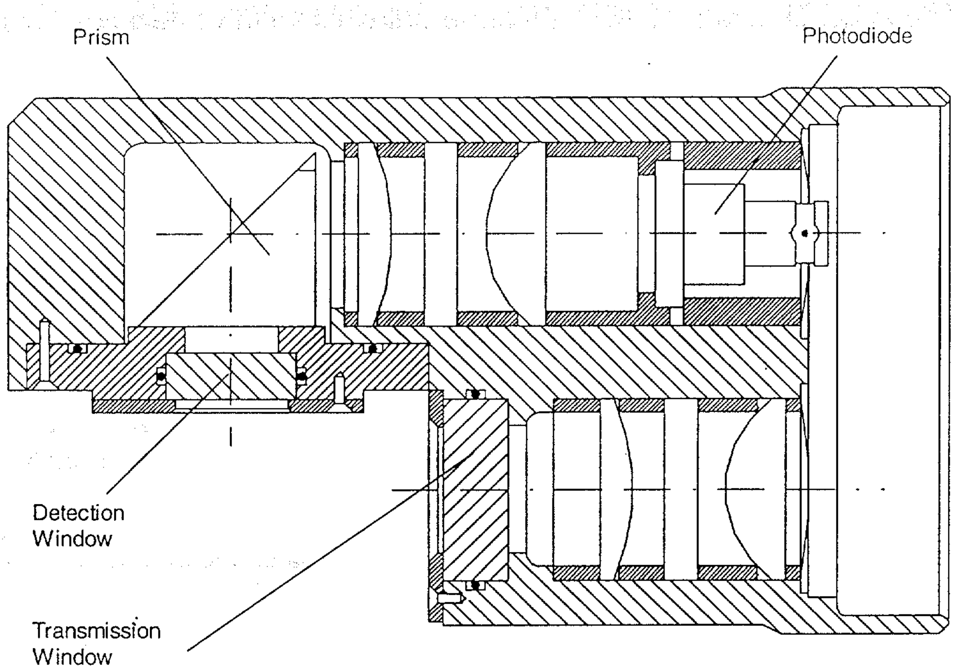

Fig.No.1 **Optical Layout**

Light from the flashlamp takes two paths, a reference beam and a detection beam. The reference beam takes a direct path to the reference photodiode with no lenses or filters. The detection beam is optically filtered then focussed out through the transmission window, illuminating the water sample in front of the detection window. Detection is by light fluorescing from the specimen passing through the detection window, via a prism, lens and optical filter onto the detection photodiode.

The intensity of the optical beam(X) returned from the specimen is compared with with the strength of the reference beam(Y) generated from the same light source. The outputs can be related to X/Y so the computed output should not be affected by variations in illumination due to flashlamp ageing. The bias voltage for the detection photodiode is derived from the ambient light compensating circuit which compensates for any ambient light that falls on the detector.

4 COMMUNICATIONS and LOGGING

• Communications

All aspects of Aquapack CTDF system configuration and data collection is controlled from the customers' PC Terminal. Chelsea Instruments use an RS422 interface link and the Deck Unit converts this to RS232 for communication with the terminal. (Default: 9600 baud, 8 bits, no parity, one stop bit.)

The Aquapack CTDF is an intelligent instrument which allows flexible configuration, data conversion and full-duplex RS422 communications. It is controlled from the terminal over a single four wire communications link. The Rx and Tx pairs at the Aquapack CTDF connect to the Tx and Rx pairs of the PC Terminals' serial interface.

All of the integral measuring instruments and on special builds any ancillary instruments are controlled via the data logger.

• Logging

The data logger is mounted on the electronics chassis housed inside the pressure housing. It samples up to 16 analogue signals into an ADC with a resolution of 16-bits. The raw conversions are either logged or sent directly up the serial RS-422 communications link. Only the raw conversions derived from the channels specified as active are stored or transmitted. These raw conversions need to be processed by the relevant algorithms to produce the related quantities in standard engineering units.

• Sensor Configuration

The instrument sensors are configured in the following order:-

0	conductivity	1	temperature (1)
2	pressure	3	fluorimeter reference
4	fluorimeter signal	5	ambient light level
6	unused	7	unused
8	unused	9	unused
A	unused	B	unused
C	back-up battery	D	primary power
E	low voltage reference	F	high voltage reference

• Logged Data

When operating in the logging mode the acquired raw data is stored in binary form to make optimum use of the logger memory. At each scan the sensors are sampled through an ADC and the resulting 16-bit integer data, along with a timestamp and checksum, is stored in the logger memory. Information relevant to the instrument and the acquisition of this raw data, is stored in a header block preceding the data area. The header is 1024-byte and the information is in a fixed ASCII coded format.

5 BATTERY OPERATION

Operation

To enable Aquapack to be left unattended and acquire data over a long period, a battery pack may be fitted as a factory fit option . To conserve battery power Aquapack has been designed with some ingenious features:

1. When Aquapack is connected to the Deck Unit or any other external power source, the battery supply is disconnected.
2. As part of the option a Sea Water Switch may be fitted which ensures that the battery supply is only available when the unit is immersed in water.
3. The logger has a 'Sleep' mode into which it will revert when ever it is not acquiring data or communicating with the system. In this mode the logger consumes minimal power and the real-time clock is supported by a back-up battery.
4. Whilst in the sleep mode the power to the flash lamp is disconnected from the lamp drive circuit .
5. As soon as the instrument is woken by the real-time clock the flash lamp circuit re-starts and data is acquired and logged.
6. At a data acquisition interval of one minute a new battery will support a 35 hour deployment at an ambient temperature of 20°C..

Battery Specification

Batteries (10 off):		Duracell MN1400		
Battery Voltage:		1.5V		
Battery Life:	at 20°C	35 hours	)	for guidance
	at 0°C	15 hours	)	only
Set Acquisition Interval **(R)**:		One minute		

Construction

The battery unit is manufactured in Nyloil, it is mounted on the electronics chassis within the pressure vessel and houses ten replaceable batteries, its position is shown in Fig.No.2. Access to allow replacement of the battery is by removal of the sensor plate assembly from the pressure vessel. The sensor head is sealed using an o'ring.

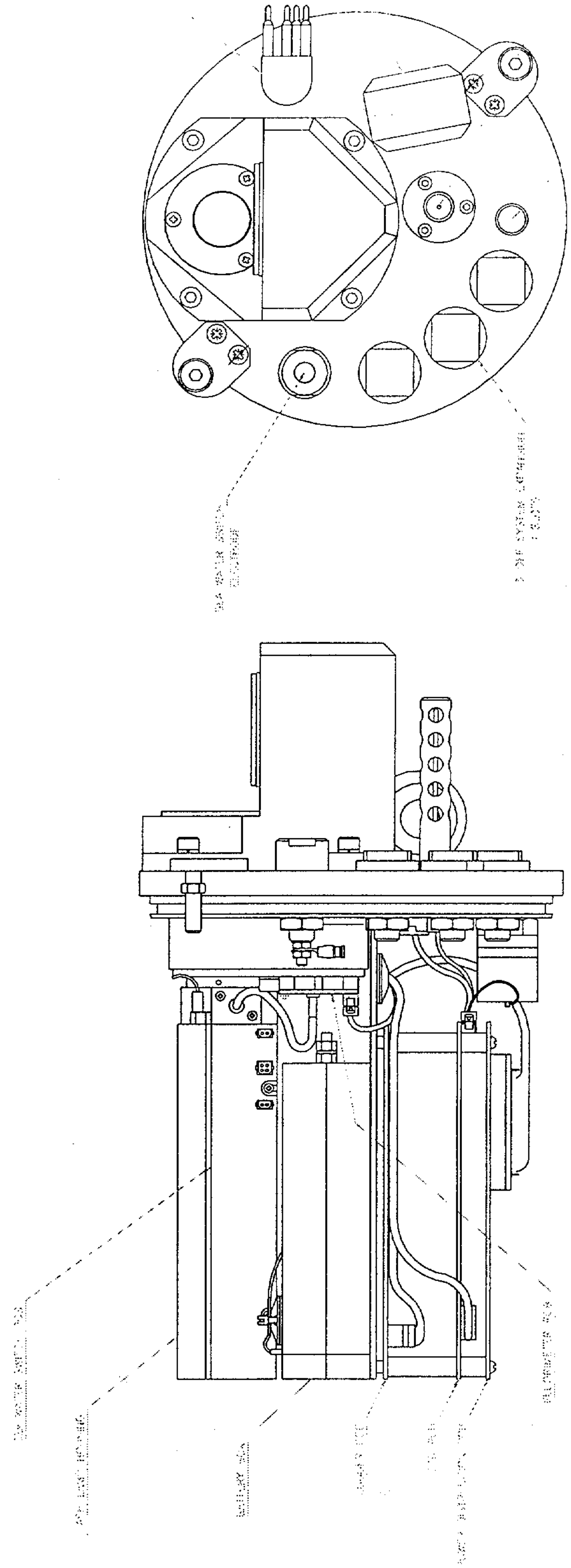

Fig.No.2 Aquapack Assembly

Product Bulletin

UV Aquatracka

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1 OVERVIEW

The UV Aquatracka (Fig. No. 1) is a compact lightweight submersible fluorimeter using a photomultiplier detector for the detection of Hydrocarbons (360nm) or Gelbstoffe (440nm), each application uses a common pulsed Xenon light source but requires a unique set of optical filters in both the excitation and emission (detection) paths.

The UV Aquatracka has been designed to use the same body size as the Mk III Aquatracka so there is a considerable reduction in size from the previous Mk 2 PMT Aquatracka. Using a standard grade 5 titanium casing the instrument may be deployed down to a depth 600 metres for the Hydrocarbons (360nm) and Gelbstoffe (440nm) variants.

The instrument is of modular design and is able to be configured (Table 1) for <u>analogue only</u> or for digital output, with or without internal storage. The analogue option being logarithmic scaled. Provision has also been made for the inclusion of a fast response (300ms) platinum resistance Pt 100 Temperature Probe option.

In the digital output version, 2 Mbytes of data logging memory is standard. Communication is via a RS422 link and the logger outputs three data channels, the fluorimeter signal, its reference signal and the temperature channel. The function of the logger is set-up from the PC Terminal via the communications interface, the period of data transfer or logging, is then maintained by the internal battery powered clock timing circuits during long term acquisition.

The Chelsea Instruments Ltd. mains/battery powered Portable Interface Unit (PL5484) is supplied separately and acts as a RS422 to RS232 converter interface for the user's PC Terminal. It also includes a power supply for the UV Aquatracka and can be used during pre-deployment set up and post trial data retrieval. Optional Battery Packs (PL4495 and PL5090) are available to allow operation of the UV Aquatracka when in the unattended logging mode.

The UV Aquatracka may be mounted on a towed vehicle such as Chelsea Instruments' Aquashuttle or SeaSoar, it can be deployed on buoys, on a mooring , or vertically in a profiling mode.

VARIANTS	360nm HYDROCARBON	440nm GELBSTOFF	DIGITAL O/P	2Mb LOGGING	ANALOGUE LOG O/P	TEMP PROBE
1	✓		✓	✓		✓
2	✓		✓	✓		
3	✓				✓	✓
4	✓				✓	
5		✓	✓	✓		✓
6		✓	✓	✓		
7		✓			✓	✓
8		✓			✓	

Table 1 UV Aquatracka Variants

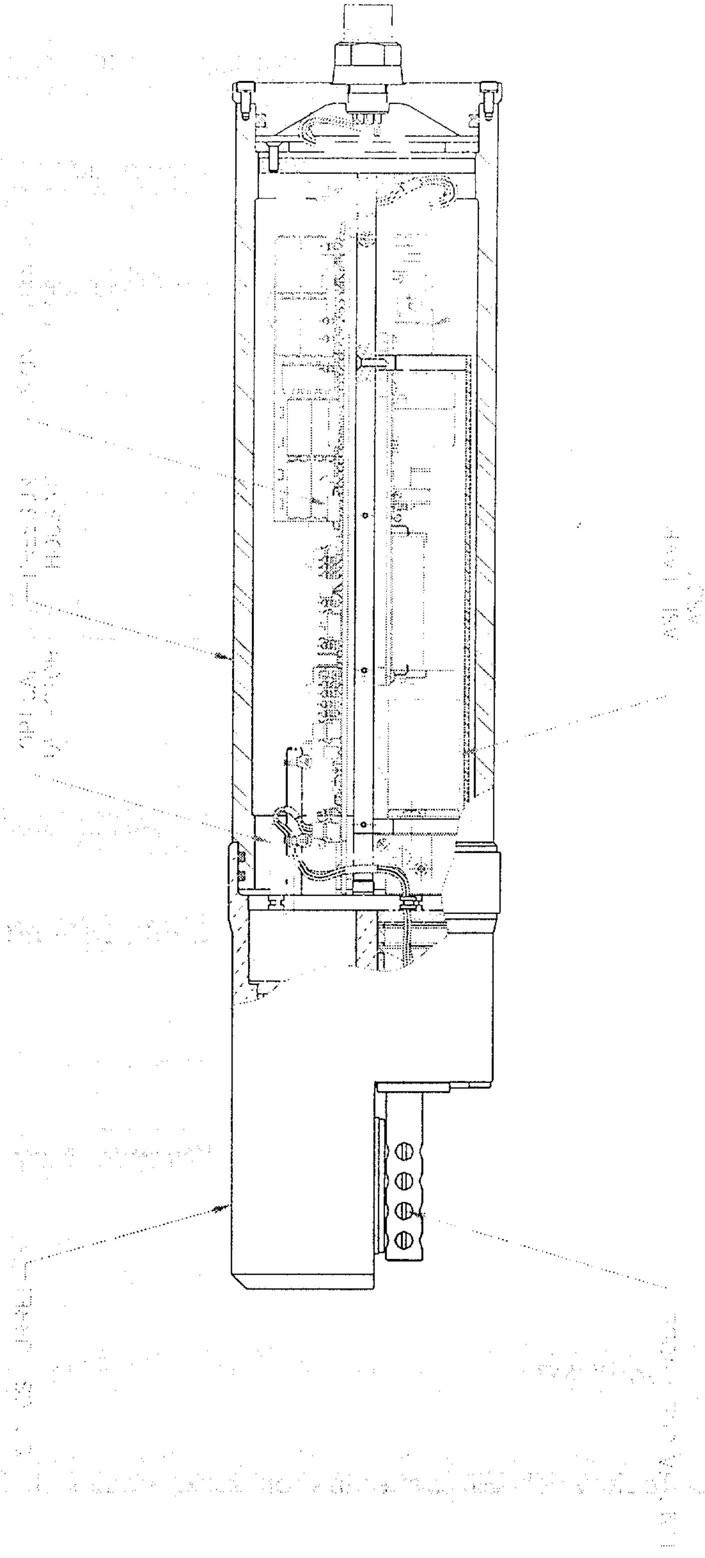


Fig.No.1 UV Aquatracka

PRINCIPLES OFOPERATION

The fluorimeter uses a pulsed light double beam technique which improves performance in a number of ways.

The functional block schematic is shown in Figure 2 and the internal layout of the instrument in Figure 1.

The pulsed technique allows virtually perfect discrimination to be achieved against 'steady' ambient light signals since the light pulse is only two microseconds long, variations in ambient intensity due to wave glitter, etc. are considered 'steady' as far as the high speed processing circuits are concerned and are effectively rejected by the Aquatracka; this is a major operational advantage. A small arc source also allows more efficient optics to be used and together with the pulsed excitation improves the signal to noise ratio, compared to DC excitation.

The double beam system allows the light intensity of the optical beam(X) returned from the specimen to be compared with the light intensity of the reference beam(Y) generated from the same pulsed light source. The outputs are then ratioed(X/Y) so that they are not affected by any variations in the flash lamp strength due to lamp ageing. Since the lamp life exceeds some 10^8 flashes it can be considered to be 'indefinite' unless the instrument is more or less continuously powered thus extending the calibration life of the instrument.

Among the special features is the use of a 'rugged' pulsed light source. Such a lamp emits copiously at visible and ultra-violet wavelengths, giving excellent fluorescence excitation of many substances, while efficiently converting electrical energy to optical output.

NOTE: The light source of the fluorimeter is small, very intense and produces copious emissions of ultra-violet, which can cause eye damage. DO NOT expose eyes to the direct beam of the light source.

Light from the flash lamp takes two paths, the reference beam and the detection beam. The reference beam takes a direct path to the reference photo diode without any lenses or filters. The detection beam from the flash lamp is optically filtered and focused out through the excitation port window to illuminate a volume of liquid specimen just above the detection port window, which is situated on the turret at 90 degrees to the excitation port. Light scattered or fluorescing from the specimen and passing through the detection(emission) port is directed via a prism, lens and optical filter onto the detection photo multiplier tube(PMT).

The bias voltage for the PMT detection amplifier is derived from the ambient light compensating circuit which compensates for some ambient light that falls on the detector. If the ambient light is excessive the PMT supply voltage is disabled to protect the PMT.

Fig.No. 2 Functional Block Diagram

SPECIFICATION

Electrical Specification

Input Voltage:		10.5 to 72V d.c. 2.88 Watts (nom. 240mA at 12V d.c.)
Inrush Current:		495mA at 12V d.c.
Outputs:	Digital	EIA-RS 422
PMT variants	Analogue	0 to 4V Logarithmic (1V per decade)
Light source:		Xenon Lamp
	Pulse Rate	4Hz
	Life	10^8 flashes
Photomultiplier Detector:		Hamamatsu H5783 - 01
Memory (Logging):		2Mbytes RAM 3 channels (140K readings per channel)
Warm-Up Time:		10 seconds
Sampling rate:		4Hz (nominal) Extend to 10 Hz (optional contact CI)

Optical Specification

- **360nm Fluorescence (Hydrocarbon)**

Detector:	Photomultiplier Tube (PMT)
Range:	0.001 to 10 µg/l Carbazole
Min. Discernible Signal:	0.001 µg/l Carbazole
Resolution:	1% of reading or Min. Discernible Signal which ever is greater.

Optical Specification (continued)

Excitation Filter Characteristics

Peak wavelength: 239 ± 4nm
Full Width Half Maximum (FWHM): 26 ± 4nm
FW at 1% TPK: 55 ± 9nm
FW at 0.1% TPK: 85 ± 13nm
Spectral Rejection: Better than 10^{-4} to infrared
Additional rejection between 300 - 400nm provided by gas cell

Emission Filter Characteristics

Peak wavelength: 360 ± 6nm
Full Width Half Maximum (FWHM): 70 ± 10nm
FW at 1% TPK: 150 ± 20nm
Spectral Rejection: Better than 10^{-4} to X-ray and 10^{-3} to infrared

- **440nm Fluorescence (Gelbstoffe)**

Detector: Photomultiplier Tube (PMT)

Range: 0.001 to 10 µg/l Perylene

Min. Discernible Signal: 0.001 µg/l Perylene

Resolution: 1% of reading or Min.Discernible Signal which ever is greater.

Excitation Filter Characteristics

Peak wavelength: 239 ± 4nm
Full Width Half Maximum (FWHM): 26 ± 4nm
FW at 1% TPK: 55 ± 9nm
FW at 0.1% TPK: 85 ± 13nm
Spectral Rejection: Better than 10^{-4} to infrared.

Emission Filter Characteristics

Peak wavelength: 430 ± 6nm
Full Width Half Maximum (FWHM): 110 ± 17nm
FW at 1% TPK: 160 ± 25nm
FW at 0.1% TPK: 230 ± 35nm
Spectral Rejection: $<10^{-4}$ X-ray to infrared.

Mechanical Specification

Size:		89mm dia. by 406mm long.
Weight:	In air	5.5kg
	In water	3.5kg
Life Expectancy:		8 years
Operating Temperature range:		-2 to +40°C
Storage Temperature range:		-40 to +70°C
Deployment Depth:		600 metres (Hydrocarbon/Gelbstoffe)

Temperature Probe (Optional)

Type:		Platinum resistance.
Range:		-2 to +32 °C
Accuracy:		0.01 °C
Resolution:	(Digital)	0.001 °C
	(Analogue)	10°C/V
Response Time:		300 ms (nominal)

2 TECHNICAL DESCRIPTION

Mechanical

The UV Aquatracka pressure housing/casing comprises three assemblies manufactured from grade 5 Titanium, the Optical Turret Assembly; a Pressure Housing and the End-Cap Assembly. The main component layout is shown in Figure 1.

The general assembly consists of four major sub-assemblies:-

1) The turret assembly that houses the optical components and windows and makes up the front cap of the pressure housing. The assembly has two plain bores machined parallel with the length of the body, for the excitation and detection (emission) optics. The optical layout is shown in Figure 3. The optical components consist of a series of lens and filters on the excitation side and lens, filters and a prism on the emission side. These are held in their correct axial positions by a set of spacers.

2) An electronics chassis that contains:

- The photomultiplier Tube(PMT) assembly
- The xenon flash lamp and its drive circuit pcb.
- The flash lamp high voltage power supply pcb.
- The fluorimeter and temperature measuring circuits pcb.
- The logger memory and RS422 communications circuits.
- The power supply regulator circuitry pcb.

The chassis is fitted with front and rear bulkheads. The front bulkhead provides the chassis to turret mounting point and when secured to the turret retains the optical components by pre-loading two waveform washers.

3) The cylindrical pressure housing assembly that encloses the electronics chassis.

4) The rear end cap assembly that seals the pressure housing and holds the interface connector.

Electrical

Most of the electrical components of the circuits of the UV Aquatracka are mounted on three pcb's. These pcb's. are:

- A signal processing pcb, which contains the analogue processing components, the microcontroller, the external analogue and digital interfaces.

- A power supply pcb, which contains the components that convert the incoming 10.5 to 72 V.d.c. supply from the Sea Cable to ± 12V and +5V supplies for the various electronic circuits.

- A lamp supply pcb, which provides the high voltage (700 to 750 V d.c.) required by the Xenon lamp.

The pcb's are linked by plug/socket to related off-board components as are the connections between the Rear End Cap and Electronics Chassis.

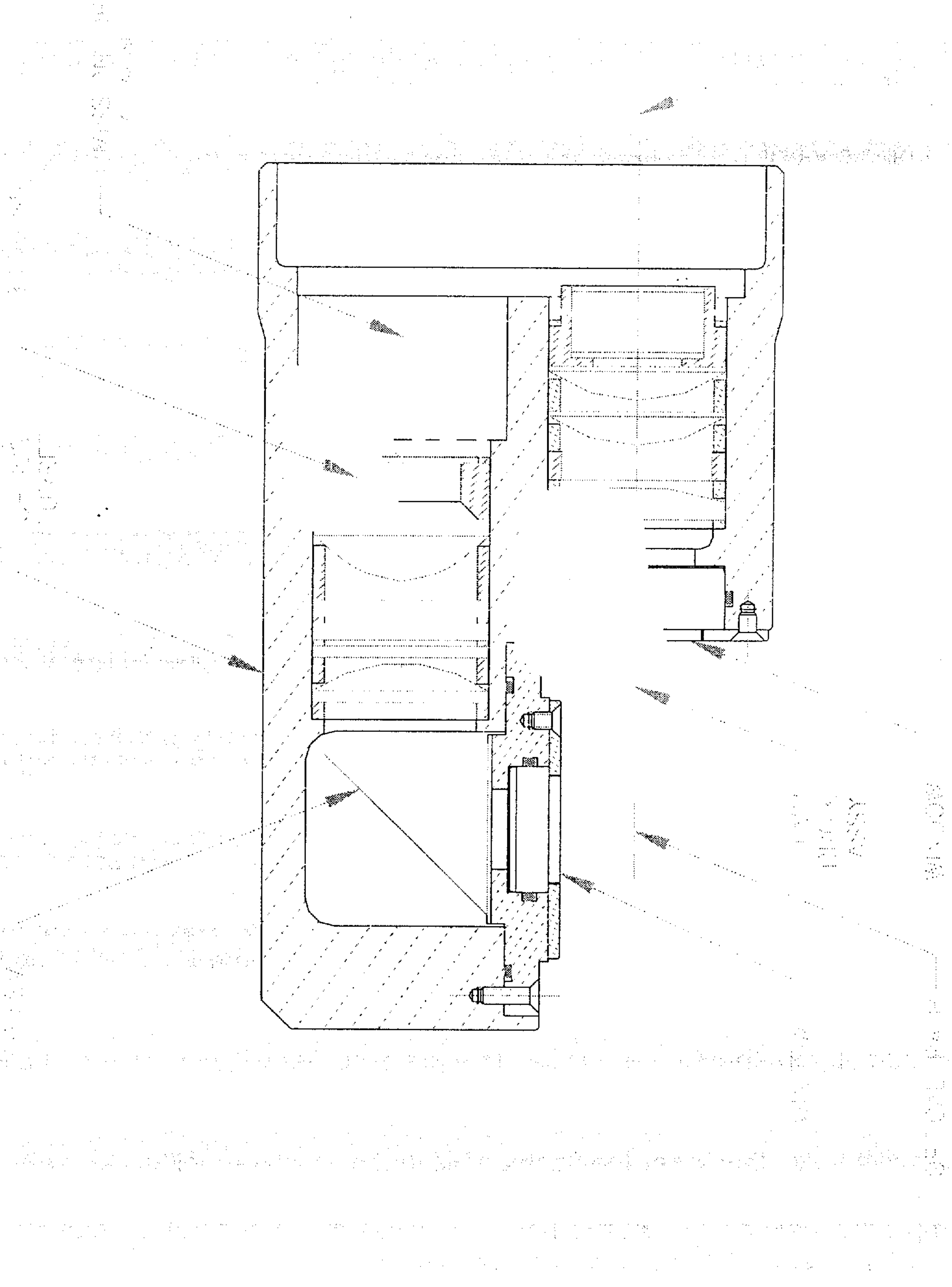


Fig.No. 3 Optical Layout

FUNCTIONAL DESCRIPTION

A functional block diagram of UV Aquatracka is shown in Figure 2. Functionally, the instrument comprises seven sections:

- Sample signal measurement.
- Reference signal measurement
- Data Acquisition Microcontroller.
- Light source
- Logic control
- Power supplies.
- Temperature probe

Sample Signal measurement

Consider the sample signal measurement section first.

The transmitted light from the light source is optically filtered and focused into a cone. This cone of light is targeted into the sample liquid, via the excitation port, to illuminate the sample immediately above the detection port.

The detection port is mounted in the turret so that it is orthogonal to the excitation port.

Light fluorescing or scattered from the sample liquid and passing through the detection port is directed via a prism, lens and optical filter onto the PMT in the signal measurement section.

An ambient light compensation circuit is included which provides some compensation against ambient light that falls on the detector. If the ambient light striking the detector becomes excessive, the output from Aquatracka is driven beyond the normal full scale value, providing a warning that this condition is occurring and the PMT supply is disabled until the ambient light level is reduced into the operating band.

The output from the PMT is applied to a pre-amplifier which is in turn applied to a sample and hold circuit.

Approximately 40 µs after the flash unit is triggered, the amplified and electronically filtered version of the PMT output signal reaches its peak value at the input of the sample and hold circuit. At this point, the value of the input of the sample and hold circuit is transferred to the storage capacitor.

The output of the sample and hold circuit, which is effectively the voltage across the storage capacitor, is applied to an input channel of the 20 bit analogue to digital converter (ADC). This is subsequently processed and output as a 16 bit digital RS422 signal or via a 12 bit DAC for analogue output

Reference Signal Measurement

The reference photo diode measures the output light source directly, with no lenses in the beam path. The reference photo diode signal is amplified and passed through a sample and hold circuit to the ADC.

Data Acquisition Microcontroller

The data acquisition/communications microcontroller is responsible for power management, control of the flash lamp, sampling timing, analogue to digital conversion, data logging, and external communications.

The signal processing pcb incorporates the following sections ;

- Microcontroller and associated circuitry
- Analogue to digital converter (ADC)
- non-volatile storage for calibration coefficients, either battery backed RAM or E^2PROM
- Digital controls, including BITE
- Analogue measurement system interface and sample and hold circuitry

Light Source

The light source is triggered by the logic control circuit at a frequency of 4Hz. When the light source is triggered, a capacitor is discharged via the resistance provided by the light source path, creating a flash of light having a high ultra-violet content.

Because the period of the flash generated by the light source is very short (approximately two microseconds), the variations of ambient light intensity caused by water wave glitter are negligible as far as the signal processing circuits are concerned. This pulsed light technique also enable almost total discrimination to be achieved against steady ambient light pick-up.

Logic Control

The logic control circuits of the instrument are used to:

- trigger the light source
- control the sample and hold circuits in the two signal processing sections.

The operation of these circuits is automatic and starts when the instrument is switched on via the Deck Unit.

Power Supplies

The incoming 10.5 to 72 V supply from the Sea Cable is routed to a d.c. to d.c. converter that produces output voltages of + 12 V and - 12 V d.c. These +12 V and - 12 V supplies are then distributed to the appropriate circuits in the instrument.

The + 24 V supply required by the power supply unit that provides the high voltage output (700 to 750 V d.c.) for the light source lamp is derived from the ± 12 V d.c. to d.c. converter, by effectively connecting these outputs in series.

Data Logger

The logger is the centre of intelligence for all communication and control between the surface, the integral fluorimeter and the temperature monitoring circuit when fitted.

The logger circuit board houses 2Mbyte of RAM memory, a 3 channel data logger and the RS 422 communications interface. (Default: 9600 baud, 8 bits, no parity, one stop bit). Data is either stored (140K readings per channel) or transmitted direct to the surface via the RS 422 interface.

The data logger has two modes of operation, Machine Mode and Verbose Mode.

- Machine Mode is used for simple communication with an intelligent top-end software system.
- Verbose Mode is used when communication is via a dumb terminal and full prompts and messages are available.

Data logging function is set by the logger commands;

'Set Acquisition Interval', etc. A battery backed internal clock circuit controls and maintains the implementation of the alarm and timing commands.

Note: To conserve power when data is not being sent or logged, in the long term data acquisition mode, especially if the optional Battery Interface Unit is used, the logger disables the lamp circuit to conserve power.

Appendix D –

Australian Geological Survey Organization (AGSO) Sniffer System

Sniffer System Description

The system is designed to be a modular which, when configured for Petroleum applications is as follows:

Towfish and Cable

A 'towfish' containing a submersible pump, echo sounder and data logger is suspended on an armoured cable. The cable consists of a nylon tubing core surrounded by 22 conductor lines for data and power transfer and has a stainless steel braided shield and an outer plastic coating for protection. Fairings are used to reduce the drag on the cable through the water. A typical tow speed for the fish during acquisition is 5 to 7 knots. The echo sounder is used in order to control the height at which the towfish is 'flown' above the sea floor. The effective working depth is around 240 metres with the current winch and cable. It is intended to extend the capability to 500 metres when our larger winch is fitted with a new cable in1999.

Data Logger

The data logger is fitted with various probes and samples: temperature, dissolved oxygen, salinity, conductivity, depth, turbidity, Ph and oxidation / reduction potential.

Winch &'A' Frame

The cable is deployed from a winch with a 2 metre diameter drum which incorporates a hub with a universal pipe coupling /slip ring assembly which allows seawater to be pumped and data and power to be transferred from the cable. The winch can be controlled remotely by joystick control when required. The cable is fed onto the winch drum in a single wrap via a sheave and screw assembly fitted to an 'A' frame.

The 'A' frame is placed at the stern of the vessel and is positioned such that it allows the towfish to be launched and recovered whilst keeping clear of the ship's hull.

Fairing Platforms

Two fairing platforms are placed between the winch and 'A' frame (where possible) to allow replacement fairings to be fitted to the cable as necessary.

Dynamic Headspace Gas Extractor ('Stripper')

Seawater pumped from the fish is sprayed into a glass chamber which has an automatic level control. A vacuum pump applies a -ve pressure to the headspace thereby extracting volatile hydrocarbons which are piped to gas chromatographs for analysis.
The extracted hydrocarbons from the stripper flow to a set of 8 parallel sample loops each of which is attached to a 10 port electronically actuated flow switching valve, housed within the oven of a Gas Chromatograph.

Gas Chromatographs

The set-up for petroleum work is as follows:
2 x Shimadzu GC17a Gas Chromatographs each fitted with four FID detectors such that there are four asynchronous acquisition channels per GC. One GC is set to do C1-C4 hydrocarbon analyses on each channel whereas the other GC is set-up for Benzene/Toluene analysis. At one minute intervals (shot points) , a set of 2 channels, one from each GC, is 'fired' simultaneously with an analysis time of just under 4 minutes. Each set of two channels is the fired every four minutes

continually. The output is then one complete set of result C1-C4 +Benzene/Toluene every minute. At 5 knots this is one set of results ~ every 150 metres of travel.

Computer Control and Software

The analogue signal from each detector is passed through an 'intelligent' interface (an A/D converter) which in turn dumps the data to a Pentium PC installed with GC integration software (Perkin Elmer, Turbochrom). The control of firing, and real-time display of analysis results is performed by AGSO designed software. All raw and processed data is electronically stored (against a shot point number) in a database on hard disk and on 120mb floppy disks. Independently acquired navigational position (dGPS) from an in-built receiver in the lab and oceanographic data from the logger in the fish are also stored on the database. This allows for an accurate geographic location of all data to be established. Third party software such as Surfer for Windows can then be used to prepare graphic presentations of the data in the search area.

Navigation Software

The Portalab is fitted with a dGPS system and Windows NT based Endeavour navigational software with a Raster Chart Display System which displays real time position, historical track with cross-course error, bearing and distance to waypoint etc. superimposed on Australian Hydrographic Office Seafarer or the British ARCS charts. The set-up should allow a split signal to be directed to the Bridge to display the same video display of route and position as seen in the Portalab

Gas Supply System

OH&S considerations and the logistics of handling large numbers of high pressure gas cylinders at sea have led us to construct a Gas Generator/Purification system which delivers the instrument grade hydrogen and air used for the FID detectors. However it has not been possible (at this stage) to do away with the need for some bottled gas, namely UHP helium, cylinders of which needs to be fixed in a collar arrangement on the outside of the 'PortaLab'

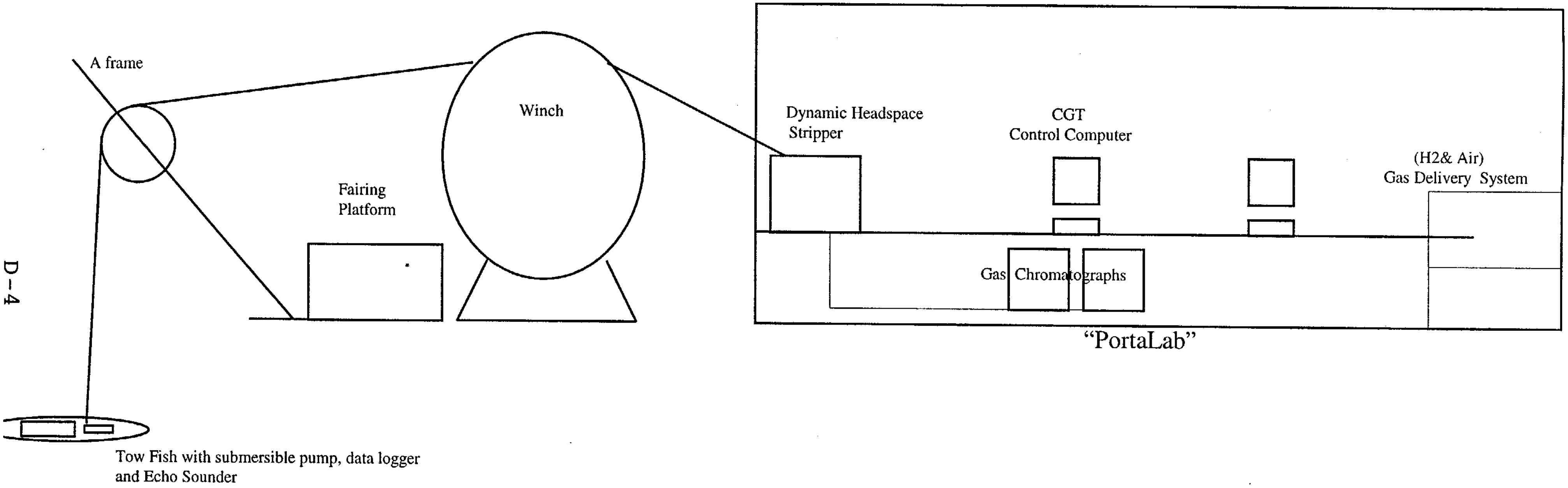
Demountable Laboratory (PortaLab)

A 20' ISO sea container fitted with insulation, air conditioning, marine grade windows and doors, laboratory benches, sink, lighting and power fittings, has been built. The winch, A - Frame, fairing platform and the portalab have been designed to minimise the logistical problems of deployment. The lab is designed to be transported as any sea container to the ship by truck, lifted by crane to the deck and welded or otherwise secured in place. Similarly the winch power pack and A- frame need to be welded or secured to the deck.

Power Requirements

The Portalab requires a 32 Amp 415V 3 phase supply. The laboratory apparatus has a 7Kva UPS system with minimum 7 minutes of backup power to run essential instruments.

The deck gear consisting of two compressors which require, 2 x 250 Volt , 10A AC supplies and an hydraulic power pack, a winch and an 'A' frame which requires 1 x 32 amp 415V 3 phase supply.



Schematic view of 'Sniffer' System

System Dimensions: