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Development and Testing of an ROV-Deployed Deepwater Subsea Sampling System

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1 INTRODUCTION

The increase in deepwater production in the Gulf of Mexico and other locations around the world has brought a corresponding increase in the use of subsea multiphase flowmeters. The placement of subsea multiphase flowmeters near the well provides improved reservoir management, well diagnostics and allocation. However, multiphase flowmeters require timely, accurate fluid properties, at meter conditions, to realize their full potential. Subsea architectures with long flow lines and risers have led to the realization that well tests and topside samples cannot meet the needs of this new measurement technology.

A method for a Remotely Operated Vehicle (ROV)-operated subsea sampling system has been developed to provide a means to capture representative fluid samples at the multiphase meter and other locations at various times throughout the life of the well. The system has been tested in a laboratory and a tank to simulate ROV deployment in subsea conditions.

One attractive feature of the sampling system is the proposed standardized interface. A standardized interface between the sampling system and the process fluid would relieve users and manufacturers from the costs and complications of proprietary systems with varied designs and procedures. The standardized interface will be made available to interested parties. This paper presents an overview of the sampling system development and testing.

2 BACKGROUND

Traditionally, samples are taken from a topside separator. An individual well is isolated, the flowline/riser is flushed with the test well's flow, and the sample is taken when the isolated well stream makes it to the topside separator. When the subsea architecture includes long subsea tiebacks, this process becomes more difficult. This process is problematic for several reasons, 1) shutting-in wells results in costly deferred production, 2) samples may not be representative due to thermodynamic and hydrodynamic changes as the fluid moves through the long flowline/riser combination and 3) flow assurance concerns (hydrates, wax, asphaltenes) may prohibit this type of sampling altogether.

Multiphase flow meters require accurate fluid properties, such as gas, oil and water density, water conductivity, oil permittivity and mass attenuation for accurate flow measurement. These properties may change throughout the life of the well, reducing the accuracy of the meter. Periodic *in situ* sampling of the fluid flowing through the meter will improve meter accuracy, thereby improving the allocation process, reservoir management and well diagnostic capability.

The need for subsea sampling is not confined to multiphase meters. Other applications that would benefit from subsea sampling include: determination of gas heating value, API Gravity, sulphur content and other fluid properties and quality parameters, detection of contaminants, and regulatory issues, such as when the governing regulatory authority asks for evidence that compositional information provided by the operator in his application is still the case.

Subsea sampling of fluids *in situ* has been done before, but with limited success [1]. Previous efforts relied on sampling systems integrated with the multiphase flow meter. In 1999, Framo provided a multiphase meter with an integrated liquid sampling system for application in the Eastern Trough Area Project. During that project, ROV-assisted liquid sampling was carried out 12 times with success [2]. The current meter includes separate gas and liquid sampling ports.

Another technology, developed in 2003 by Christian Michelsen Research (CMR) and the University of Bergen, was an "autonomous metering station" with an integral sampling system. The intent was to avoid transporting fluid samples via ROV. A later concept using the sampling system as a standalone system, in conjunction with an ROV was proposed. One study [3], mentions the integrated version of the sampler, but does not mention the stand-alone version. The discussion focuses primarily on the determination of fluid properties after sampling and does not mention a stand-alone sampling system. Communication with CMR indicates that the project is still in the research and development stage.

The interest in subsea sampling has increased in recent years. Several efforts to develop subsea sampling systems are underway. In 2010, a flow through system in which samples sufficient to support multiphase meters was discussed [4]. Other recent developments include the MARS PS liquid sampling system by Cameron [5] and the Mirmorax Subsea Process Sampling System [6].

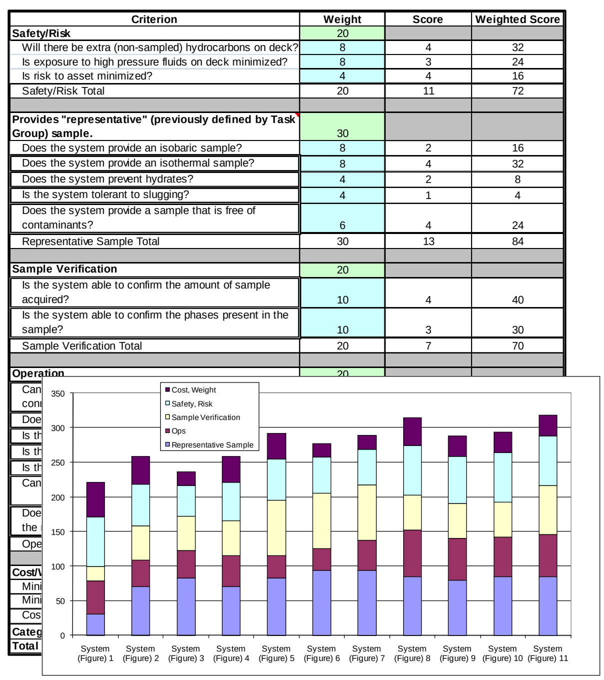
This project was a part of RPSEA Project DW1301. DW1301 consisted of 6 tasks intended to address technology gaps in deepwater subsea multiphase measurement. Development of a subsea sampling system was one of those tasks. The effort was supported by a task group consisting of representatives from BP, BHP Billiton, ConocoPhillips, Shell, Statoil and Total. In addition to monetary support, the Subsea Sampling Task Group actively contributed operations and engineering expertise throughout the development process.

3 SUBSEA SAMPLING SYSTEM DEVELOPMENT AND TESTING

3.1 Development Process

The system was developed as an industry consensus design, drawing from the expertise of several industry leading experts in the area of subsea engineering, multiphase measurement and fluid sampling and analysis.

A disciplined, requirements-driven design approach was used to ensure all stakeholder input was addressed. The initial development step was to conduct a workshop during which the project mission statement, a consensus view of system requirements, design constraints and concept selection criteria were agreed to. Sampling system manufacturers were invited to participate in the workshop. Particular attention was paid to prior art to ensure the system and its implementation did not infringe on existing intellectual property. Following the workshop, eleven concepts were generated, along with criteria for judging each concept, based on the requirements developed during the workshop. Each concept was rated based on its ability to meet the requirements. The highest rated concept was selected for development. Once the concept was selected, the project moved into the design



Criterion	Weight	Score	Weighted Score
Safety/Risk	20		
Will there be extra (non-sampled) hydrocarbons on deck?	8	4	32
Is exposure to high pressure fluids on deck minimized?	8	3	24
Is risk to asset minimized?	4	4	16
Safety/Risk Total	20	11	72
Provides "representative" (previously defined by Task Group) sample.	30		
Does the system provide an isobaric sample?	8	2	16
Does the system provide an isothermal sample?	8	4	32
Does the system prevent hydrates?	4	2	8
Is the system tolerant to slugging?	4	1	4
Does the system provide a sample that is free of contaminants?	6	4	24
Representative Sample Total	30	13	84
Sample Verification	20		
Is the system able to confirm the amount of sample acquired?	10	4	40
Is the system able to confirm the phases present in the sample?	10	3	30
Sample Verification Total	20	7	70
Operation	20		

Fig. 1 - Design Concept Evaluation

phase. Design reviews were held at the preliminary design stage and at the final design stage. Analyses and tests were planned and executed with input from the member companies. Member companies were invited to observe all tests.

"Representative" Sample

In supporting subsea metering requirements, rather than typical reservoir engineering requirements, it is not necessary to know the phase fractions. For the purposes of multiphase metering, only the properties of the phases present are required. In this project, a representative sample was redefined as "a sample containing each of the phases present at the meter, where each phase has the same composition as those at the meter."

System Requirements

Top level system requirements were agreed on during the initial design workshop. JIP members agreed that the system should:

1. Be able to function in subsea environment.
2. Operate at process temperatures of 10,000 psia and 250 deg F.
3. Not interrupt production while sampling.
4. Minimize leak paths and emissions.
5. Be safe to handle.
6. Be able to collect sufficient amounts of each phase.
7. Be ROV-operable.
8. Incorporate a standardized interface to the production fluid.

Concept of Operation

Several possible operating scenarios were considered. In the end, the group agreed that the concept should allow the ROV to accomplish other tasks while sampling is underway. So an ROV-operable concept was agreed to. One or more sampling modules can be deployed and operated by the ROV (Figure 2). The module would connect to the pipe via a proposed standard interface located somewhere near the multiphase meter or at other locations of interest.

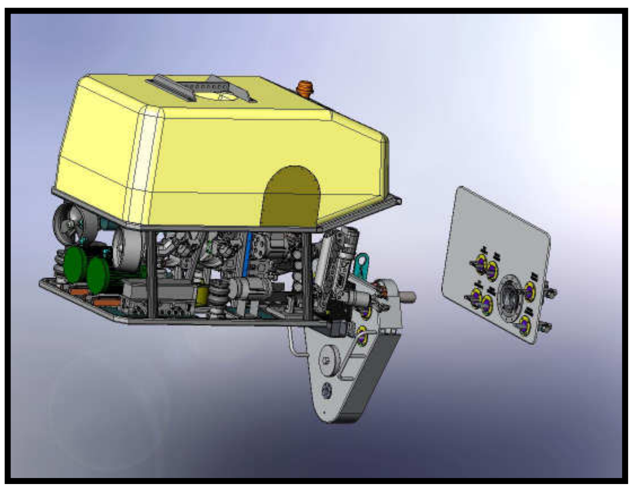


Fig. 2 - Concept of Operation

3.2 Sampling System

The concept selected for development is shown in Figure 3. The flow-through system uses the pressure differential across the production choke or another source of differential pressure to transport the sample through the sample bottle. The system is equipped with a methanol injection line to be used to purge sample lines. Multiple sampling points are selectable.

A photo of the prototype system is shown in Figure 4. An interface couples the system to the pipe to allow sample collection. The interface uses standard components available throughout the industry, enabling easy reproduction for use in proprietary sampling systems. The system can be operated by a single working class ROV.

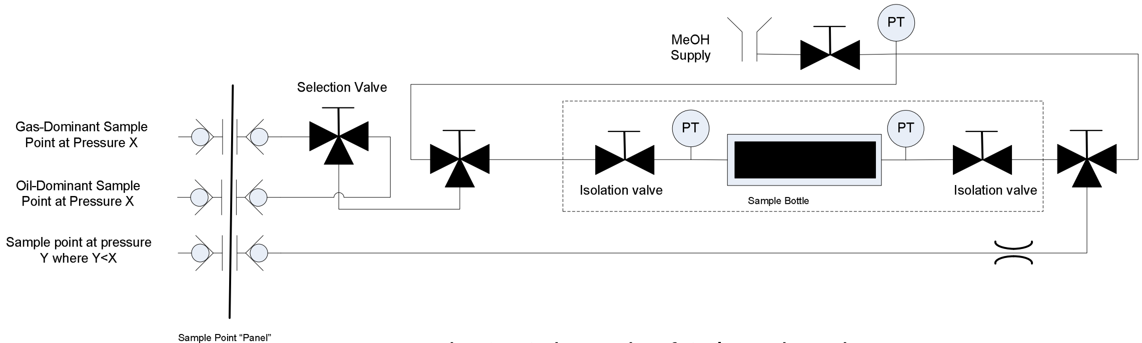


Fig. 3 - Schematic of Selected Design

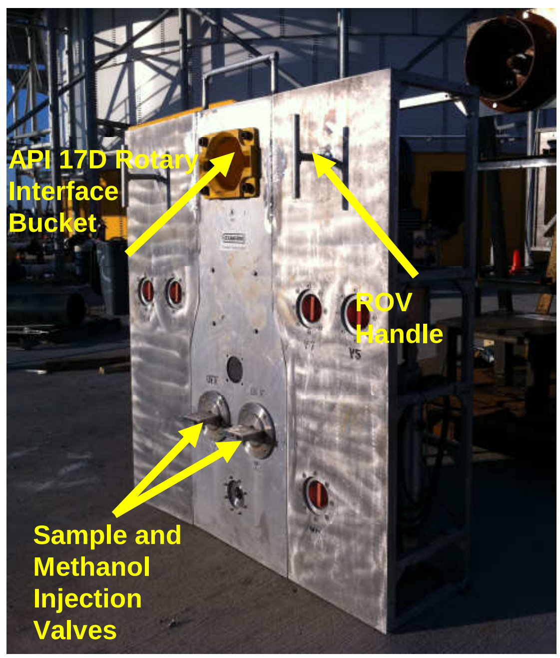


Fig. 4 - Prototype Subsea Sampling System

3.3 Sampling System Interface

The proposed standard interface (Figures 5 and 6) uses a male/female junction-plate mechanism. The male side of the mechanism is mounted to the sampling system. The female side is mounted near the multiphase flow meter. Sample lines are connected from the female side to the sample points of interest. The system is manipulated into the female side of the J-Plate for initial mating by the ROV. An API 17D Rotary Interface Bucket ("Torque Tool Bucket") is mounted on the ROV side of the interface. Using a torque tool, the ROV actuates a locking mechanism to couple the two components and establish the fluid connection.

The interface uses standard hydraulic coupling components for subsea use with ROVs, manufactured by National Coupling Company and rated to 15,000 psia. They use a poppet check mechanism so only a small volume of production fluid is released when they are decoupled. The interface is compatible with production process fluids (petroleum, water, methanol, glycol etc.).

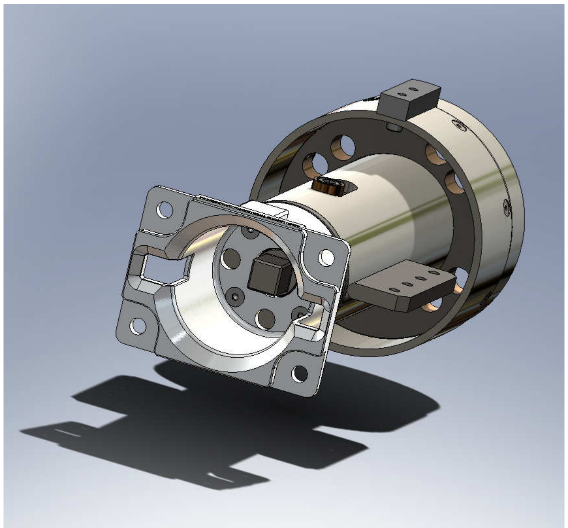


Fig. 5 - Proposed Standard Interface (Coupled)

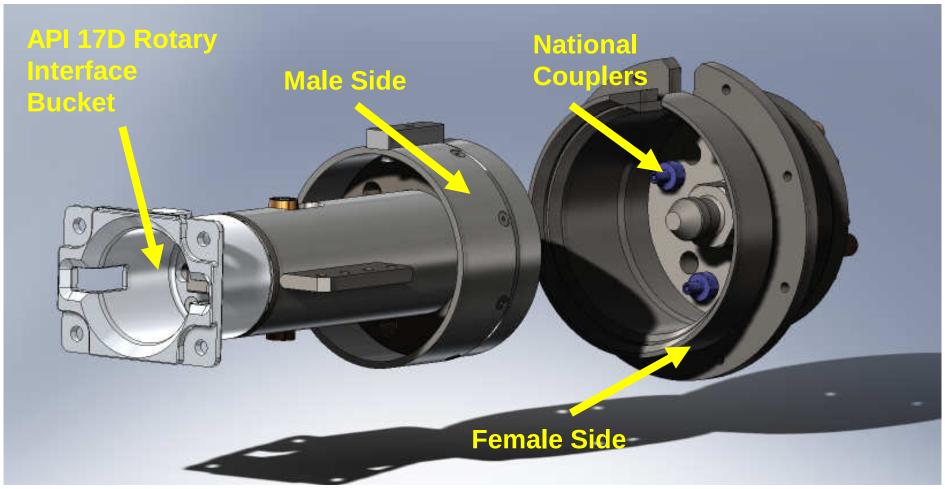


Fig. 6 - Decoupled Interface

3.4 Design Analysis

TUV NEL was asked to analyze the design to provide insight into the performance of the system during sampling in situ. The objectives of the analysis were to assess the system's ability to collect a "representative" sample and to identify design features that could impact the system's ability to collect a "representative" sample. The technical approach was to model the overall phase behaviour of a characterized live fluid as it moved through the system.

3.5 Testing

Two series of tests were conducted to establish the feasibility of sampling using the system: a flow test and a tank test. The flow test, intended to show that samples could be successfully acquired and that sufficient amounts of process fluids could be collected, was conducted at the Southwest Research Institute's Multiphase Flow Facility located in San Antonio, Texas. The second, intended to show that the system could be manipulated and successfully coupled in a subsea environment, was conducted at Oceaneering's ROV Test Tank located in Morgan City, Louisiana.

Flow Tests

The objectives of the flow tests were to gain confidence in the system's ability to collect oil, gas and water in sufficient amounts, sampling from several locations, collecting samples from at least one gas-rich regime and from at least one oil-rich regime and sampling at low and high water cut flows.

Since a flow loop test using live fluids was impractical, it was decided to use Drakesol 205, nitrogen, and saline water to model a production fluid. Nitrogen was selected, rather than methane based on SwRI's concern that the prototype system included non-explosion-proof electrical components.

Table 1. Compositional Makeup of Drakesol 205.

Component	Carbon No.	Volume Percent
Undecane	C_{11}	2.9
Dodecane	C_{12}	23.9
Tridecane	C_{13}	49.3
Tetradecane	C_{14}	19.9
Pentadecane	C_{15}	3.5
Hexadecane	C_{16}	0.5

Rather than vary water cut, which would require a significant amount of facility time, it was decided to keep the water cut at a low fraction. The rationale being that if the system could collect a sufficient amount of water at a very low water cut, it certainly could collect enough at higher water cuts. The approximate test conditions were:

- Liquid flow rate: 1500 B/D and 4500 B/D.
- Gas volume fraction: 10% and 80%
- Water to liquid ratio: 2%
- Salinity: 3.0%

Liquid flow rate references included a 1-inch Micro Motion model DH100 Coriolis meter, covering the range from 498 bbl/day to 2,523 bbl/day and a 3-inch Micro Motion model DH300 Coriolis meter, covering the range from 898 bbl/day to 4,515 bbl/day.

Fig. 7 - Determining Watercut

The gas flow rate reference meters included a 3-inch orifice meter, using plates of various beta ratios, and a ½-inch Coriolis meter. The gas flow rate was calculated according to American Gas Association (AGA) Report Nos. 3 and 8. A coalescer filter-separator installed downstream of the horizontal gas/liquid separator removed entrained liquid prior to gas flow measurement.

Once the oil and water flow rates were set, two liquid samples were collect and centrifuged to separate the oil from the water. The watercut from each sample was averaged to determine the reference watercut. Oil and water flow rate and the total system liquid content were adjusted to maintain the target watercut.

Samples of the salt-in-water solution used during the testing were collected and analyzed using a salinity refractometer. Samples collected from the actual flow loop inventory on two test days contained 3.0% wt. NaCl and 2.8% wt. NaCl, respectively.

Six sample locations near a "mixing" tee located upstream of a simulated Venturi (fabricated using two reducers), with upward and downward flow, were selected. The locations, shown in Figure 8, were selected to provide differently "biased" samples. Three spot samples were taken at each condition and at each point to provide a reference and a statistical measure of the repeatability of the reference at a given point.

Liquid samples were collected in one liter bottles and separated to estimate the amounts of Drakesol and water in the sample. Gas amounts were estimated using a sight glass installed in the sample cylinder.

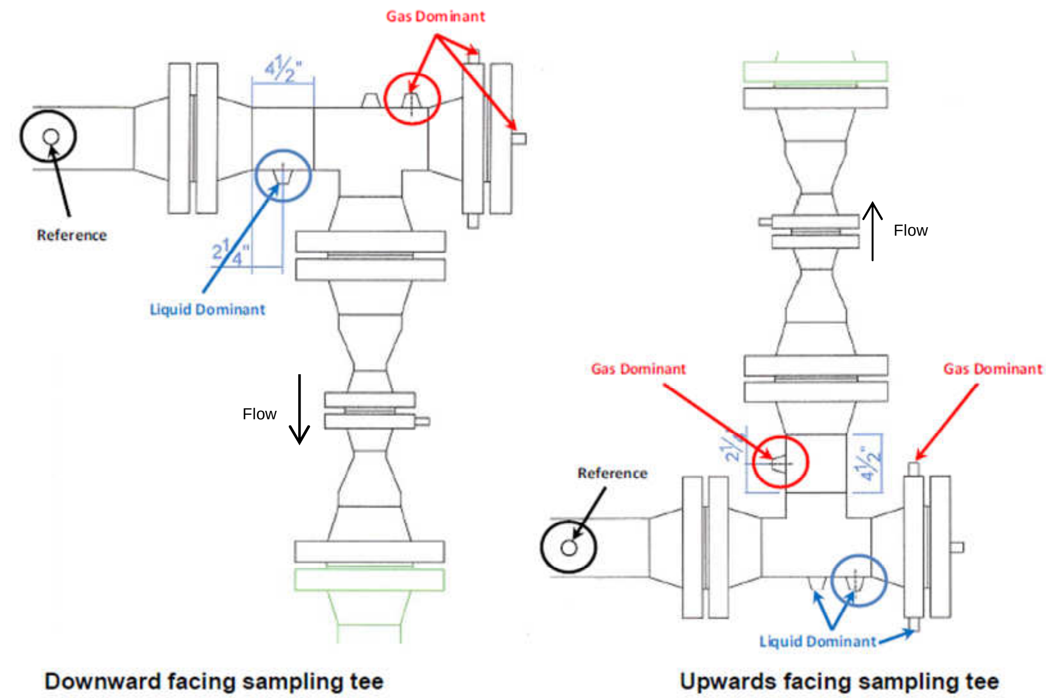


Fig. 8 - Sample Locations

Tank Test

The system was transported to the Oceaneering ROV Tank Test Facility in Morgan City, Louisiana for tests with an actual ROV. The objective of the tank test was to run through at least one operational cycle consisting of manipulating the system into position on a test stand, making a successful coupling, manipulating the valves, then decoupling and removing the system from the test stand.

Fig. 9 - Loading Sample System into Tank

The Tank Test Facility is a closed, continuously filtered, fresh water tank with a volume of 447,000 gallons. Tank dimensions are 56 ft. diameter x 25 ft. deep. Four observation windows are located near the bottom of the tank. The ROV was an Oceaneering Millennium Plus.

The ROV, test stand and sampling system were lowered into the tank. The test stand was placed near a tank wall to allow room for the ROV to manoeuvre. After ROV pre-flight tests, the operator moved the system into position on the test stand, successfully coupled it using a torque tool, manipulated the valves, then decoupled the system from the test stand.

Fig. 10 - Simulated Sampling Interface

4 CONCLUSIONS

- The TUV NEL analysis showed that minimal sample distortion was expected within the sampling system and that sample distortion was dependent on both system and ambient conditions.
- The relative percentages of oil/water/gas captured in the sampling system will not necessarily be the same as the percentages in the well head flow stream. The oil/water/gas contents of the two samples are related to the sampling location, the rate of oil and gas flow, the local multiphase flow pattern at the sampling location, and the rate at which the sample is drawn into the sampling system.
- It was possible to collect a significant amount of water, even under low watercut conditions.
- Tank tests indicated the system was challenging to manipulate subsea. However, with practice, the operator was able to successfully couple the system and manipulate the sampling valves.
- The system performed generally as expected during the flowing and tank tests.

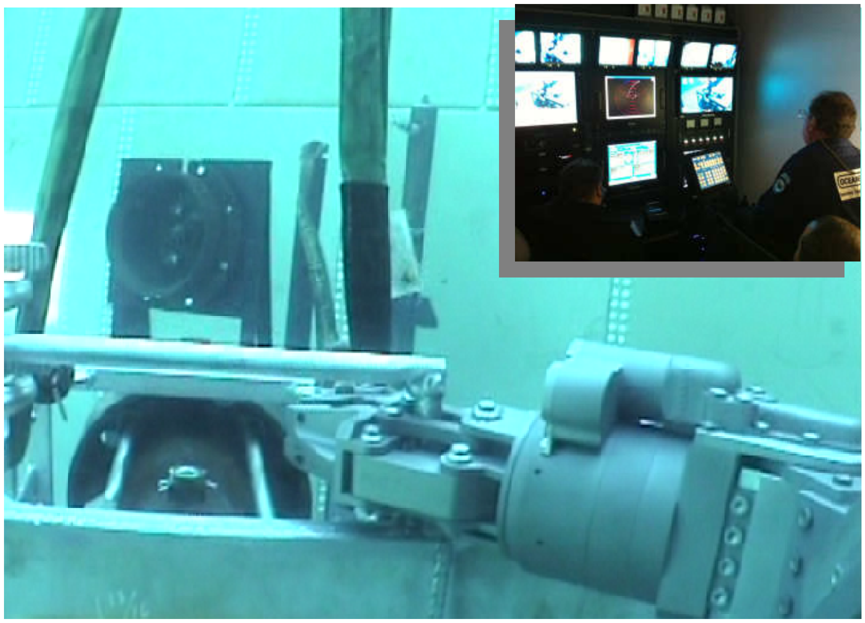


Fig. 11 - Manoeuvring the Sample System into Position

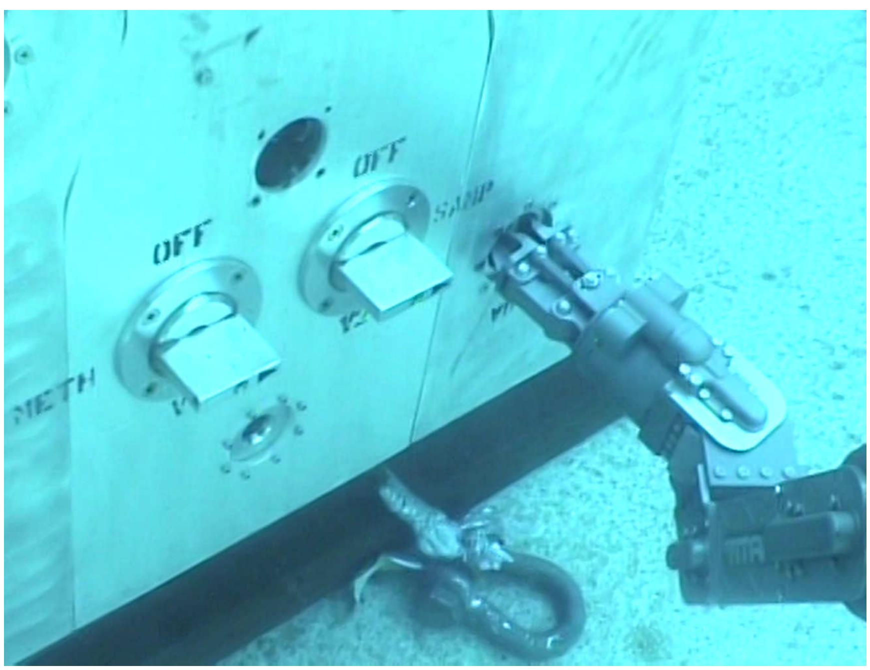


Fig. 12 - Manipulating the Sample System Valves

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