NORBIT

BSEE

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1. Document revision history

Rev. #	***Description***
1d	Preliminary report
2d	Preliminary report
3d	Final Report

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2. References

1. E17PC00013_Solicitation.pdf
2. MSL Case Report 18-002.pdf

3. Project General Information

This work has been performed as part of the project E17PC00013 (see Ref 1.) issued by BSEE Acquisition Operations Branch. This acquisition has been conducted by BSEE using Federal Acquisition Regulation (FAR) Part 15 under North America Industry Classification System (NAICS) Code 541360, Geophysical Surveying and Mapping Services. The contract type is firm-fixed-price.

3.1. Introduction and background

The Bureau of Safety and Environmental Enforcement (BSEE) promotes safety, protects the environment, and conserves energy resources offshore through vigorous regulatory oversight and enforcement. BSEE is the United States' regulator of offshore energy exploration, production, and development. BSEE's jurisdiction and regulatory responsibilities are defined by the Outer Continental Shelf Lands Act (OCSLA), which outlines federal responsibility over the submerged lands of the Outer Continental Shelf. BSEE ensures compliance with provisions of other federal laws, including the National Environmental Policy Act, the Clean Air Act, the Clean Water Act, the Federal Oil and Gas Royalty Management Act, and the Oil Pollution Act of 1990.

For more than 25 years, BSEE (and former organizations) have aggressively maintained a comprehensive, long-term research program dedicated to improving oil spill response options. The major focus of the program is to improve the methods and technologies used for oil spill detection, containment, treatment, recovery and cleanup. There is an ongoing oil discharge from the Mississippi Canyon area in the Gulf of Mexico leading to daily sheening. The specific source(s) of discharge at the site are not fully known. BSEE is proposing that reliable technology, deployed underwater, can be effective in tracking oil leaks and plumes in the water column with minimal false positive results.

4. GOALS AND OBJECTIVES

The goals and objectives of this project are as follows:

C.2.1 Deploy sensor packages from a remotely-operated vehicle (ROV) to survey, detect, and map the location(s) of hydrocarbon emissions that are responsible for the surface oil spill and/or sheen footprint in the Mississippi Canyon Area.

C.2.2 Gather data to be used by BSEE in a subsequent hindcasting assessment of sedimentation rates at the site.

5. C.3 SCOPE OF WORK

Conduct a multi-day, three-part survey covering the area of interest (1,000 ft. x 1,000 ft.; georeferenced charts to be provided) supported by a ROV intervention or multi-service vessel with an ROV outfitted with oil spill detection and recognition system. The ROV will also include a standard camera/sensor package (e.g., standard-/high-definition cameras, CTD profiler, and sector-scanning sonar) and the option for mounting/powering a broadband, high-frequency echo sounder.

The integrated oil spill detection and recognition system should consist of two 3D sonar systems, video camera with lights and other proposed sensors. The broadband, high-frequency echo sounder will be similar to most standard ROV-deployed units and provided by a partnering Federal agency prior to mobilization.

5.1. Phase 1 - General Bathymetric Survey.

The operation to identify the location(s) of the sheen source(s) starts with the high-resolution bathymetric survey of the area under consideration using 3D scanning sonar looking down. The survey will collect the bathymetry data, as well as full water column data. The preliminary analysis will result in general bathymetry models of the area and water column analysis looking for suspended plumes and the morphology of the potential sheen source(s). The preliminary analysis may also be able to identify the origin/location of the potential sheen source(s) at this point. The objective is, however, to perform general survey and to locate any potential hazards in the area, either suspended in the water column or on the seabed.

5.2. Phase 2 - Precision Bathymetric Survey.

After the preliminary processing is done and all potential hazards are identified, the secondary bathymetry survey will be performed from lower altitude to obtain a higher resolution of the mapped area. If the option for the echo sounder is chosen, the sensor will also be utilized during this part of the survey to attempt detection and quantification of any hydrocarbons in the survey area. When the precision bathymetric survey is finished, the data will be analyzed for the potential leaks. It is expected that even small leaks will be detected at this point.

5.3. Phase 3 - Source Recognition Survey.

Since the entire chart will be georeferenced, once the area(s) of interest is located, the source recognition component will start with the ROV navigating to that particular area and use the sensor packages to classify the sheen source and verify it contains hydrocarbons. The ROV will approach the suspected area for the verification and classification of the sheen source(s) and accurate documentation of the location(s). After the survey effort is complete, the bathymetric deliverables will be used by BSEE for hindcasting/assessment of sedimentation rate projections cited in prior National Environmental Policy Act (NEPA) analyses.

6. Survey planning

The original plan is outlined in Ref. 1. and repeated for convenience below.

C.4.4 Task 4: Conduct Multi-day Remote-Sensing Survey

The Contractor shall conduct a Multi-day Remote Sensing Survey based upon the Contractor's capabilities and the Survey Plan developed under Task 3 and as mutually agreed upon by the Contractor and BSEE. The survey days shall be structured as follows:

Days 1-2: Mobilization. The vessel will be prepared for the ROV operations. The working containers will be mounted on the vessel and sensor apparatus will be attached/configured to the ROV for the operation.

Day 3: Transit to the Survey Area. The transit from the vessel service port to the proposed survey area in Mississippi Canyon (MC).

Day 4: General Bathymetric Survey. Before the general bathymetry survey starts the ROV will be prepared and checked for all subsystems. The navigation checkup will be conducted as well as the patch test in a flat area. After the navigation systems are checked the general bathymetry survey will be conducted with the ROV surveying at 50m above the bottom. If possible, the area(s) of interest (potential sheen source location(s)) will be identified.

Day 5: Precision Bathymetric Survey. The precision bathymetry survey will require the ROV to be run at a lower altitude to be determined by the Contractor. If the option for the echo sounder is chosen, the sensor will be employed to detect and quantify of any hydrocarbons in the survey area. The precision survey will be followed by onboard processing of the collected data and identification of the potential sheen source area(s).

Day 6: Source Recognition Survey. Source recognition will consist of navigating the ROV in close vicinity of the area(s) of interest identified in the bathymetry surveys. The ROV operator will ensure the proper orientation of the ROV to ensure the best possible visibility of the source site(s) for the cameras and laser.

Days 7-8: Redundancy Days. Two extra days built into the schedule if the survey needs to be extended due to unforeseen events

Day 9: Transit back to the Service Port.

Days 10-11: Demobilization.

The executed mission schedule were performed as planned as follows:

September 6th - 9th - ROV Payload Integration at SeaTrepid's facility in Louisiana and survey vessel mobilization at Bordelon Facility, Houma, LA.

September 10th - 16th Survey (incl. transit and redundancy days)

September 17th - 18th - Demobilization, at the Bordelon Facility in Houma LA.

7. Draft Survey Findings and Raw Data Report

From Ref. 1.

C.4.5 Task 5: Draft Survey Findings and Raw Data Report

The Draft Survey Findings and Raw Data Report will include, at a minimum, the following:

C.4.5.1 The integration report with the photos and description of the oil spill detection and recognition systems. If the option for the echo sounder is chosen, information collected by the partnering Federal agency will be provided to the Contractor for the report.

C.4.5.2 The complete set of raw data from the sensors used for all analyses during and after the survey. It will include raw bathymetric data from sheen source detection and laser data as well as the processed data. The raw data from the echo scope will be the responsibility of the partnering Federal agency and submitted to BSEE under separate agreement.

C.4.5.3 The video footage and the photos taken during the survey.

C.4.5.4 A location plat/map outlining the survey area, the location(s) of any identified debris, infrastructure, and the location(s) of any sheen source(s) detected and verified. The plat/map shall be at an appropriate scale (as proposed by the Contractor, subject to approval by the Government) with Differential Global Positioning System (DGPS) accuracy and include precise location coordinates for all the associated items.

7.1. Deliverables and Tasks:

Task	What is required by contract	Status from NORBIT
Task 5, C.4.5.1	The integration report with the photos and description.	All included with this report.
Task 5, C.4.5.2	The complete set of raw data from the sensors used for all analyses during and after the survey. It will include raw bathymetric data from sheen source detection and laser data as well as the processed data.	All included with this report.
Task 5, C.4.5.3	The video footage and the photos taken during the survey.	All included with this report.
Task 5, C.4.5.4	A location plat/map outlining the survey area, the location(s) of any identified debris, infrastructure, and the location(s) of any sheen source(s) detected and verified.	All included with this report.

8. Mission preparation

To satisfy the mission objectives, NORBIT Subsea has developed a modular sensor suite to detect, recognize and classify underwater oil leakages called **SpiDeR** (**Spi**ll **De**tection and **R**ecognition). The following chapters outline the system characterization in the view of the goals of the mission. SpiDeR integration efforts with ROV were conducted two days before planned vessel mobilization according to mission planning documents. The mission was multidisciplinary efforts combining the operations of the NORBIT and specialized acoustic devices from NOAA according to the contract outline.

9. SpiDeR – Spill Detection and Recognition system

SpiDeR is a modular sensor suite capable of detecting, recognizing the source and classifying the hydrocarbon underwater leaks. The module can be installed on any type of ROV vehicle and interfaces to the ROV with a single cable conducting the power and data. The sensors being part of SpiDeR are listed in the Fig. 1 and consists of three sonar systems, lights, video camera, pan and tilt mechanism and the fluorescent laser based unit LIF – Laser Induced Fluorescence detection unit.

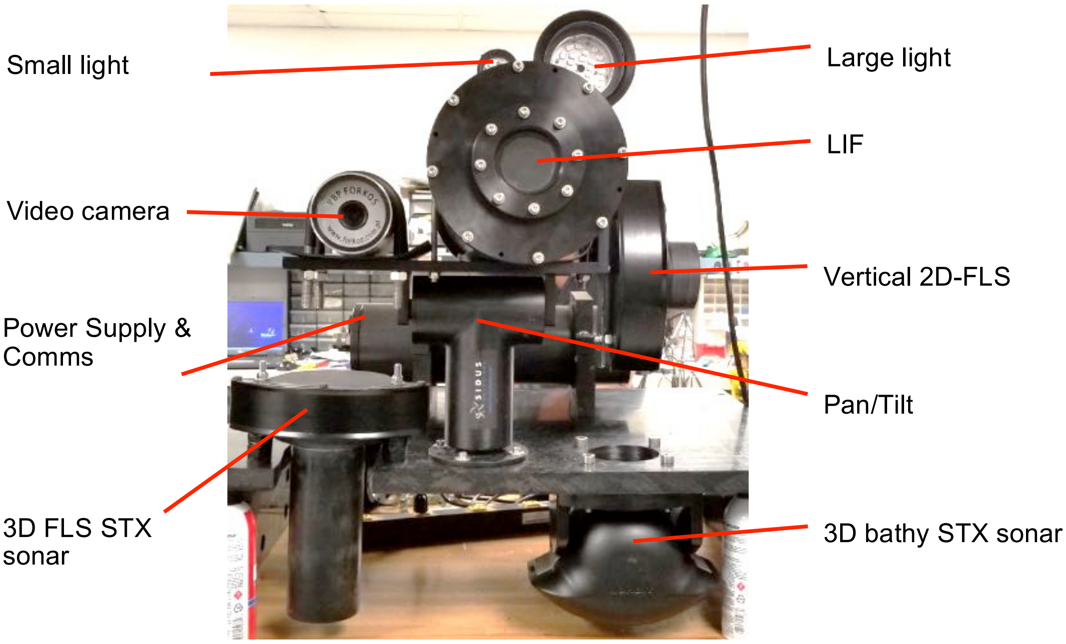

Fig. 1 SpiDeR modular system and its components

All devices are connected to the pressure vessel which contains necessary power conditioning and data connections. It also passes the trigger and timing information from SpiDeR to ROV over the same cable.

SpiDeR is powered with 48V with 6A current capabilities. The power consumption of the entire module depends on the use scenario and varies between 100W and 250W.

There are 2D multibeam, camera, lights and LIF detector unit which are mounted on the pan and tilt mechanism allowing free rotation in horizontal and vertical planes. The video camera is capable of recording the video but also periodically taking still high-resolution images. This feature has been found very useful in analyzing the plumes. The 2D Forward Looking Sonar (FLS) is mounted vertically allowing for wide vertical coverage (180deg) and offers excellent navigation and visualization aid. It is also equipped with the object detection capabilities useful for autonomous missions.

The LIF (Laser Induced Fluorescence) detector is used as classifier whether the leak contains the hydrocarbons or not. It is a point source and needs to be positioned in a close vicinity of the plume to perform detection. The range will depend on the turbidity of the water.

There are two 3D scanning systems, which are affixed to the base plate. One of the 3D scanning sonars is pointing down and is used to perform bathymetry operation similarly to other NORBIT bathymetry systems.

The STX 3D&4D imaging sonar is shown in Fig. 2. is based on a proven WBMS platform but the transmitting antenna has a new capability of electronically changing the direction of the emitted sound wave. That process is called beam steering or similarly to the receiving beamforming called transmit beamforming operation. The transmit and receive beamforming processes are outlined in Fig. 3.

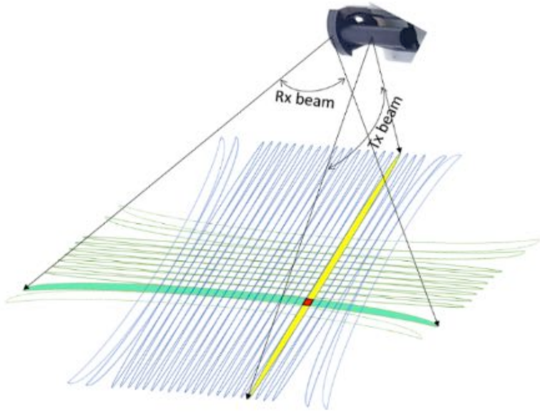

Fig. 2, NORBIT STX - 3D&4D multibeam

Fig. 3, Transmit and receive beamforming in STX

The most useful capabilities of the NORBIT STX sonar system is the ability to generate 3D imagery (bathymetry or raster image) even when the vessel is not moving. That combined with time gives 4D observable capabilities of the STX. The 4D capabilities have been demonstrated during the u-bathymetry part in Phase 2 and forward looking 3D in Phase 3 of this mission.

Perhaps the most challenging problem for reconnaissance and recovery operation using underwater acoustic equipment is the inability for the acoustic wave to penetrate hard structures and consequent shadows causing gaps in the coverage. While for some application it is desired to see shadows (e.g. mine-hunting and side-scan operation), for bathymetry mission the goal is to cover as much of the sea bottom as possible and eliminate the unwanted holidays in coverage. In some cases, it is possible to go around the structures with the vessel and fill up the gaps, but in other cases, it may deem impossible due to the presence of structures or lack of access or time. In such cases, the mission operators do not need to live with gaps in the data from these areas and can utilize the NORBIT STX.

The STX with its unique capabilities to steer the transmit beam can also “look” behind the structures in a way that standard multibeam cannot. It also allows for a more accurate representation of the underwater structures as it increases the number of observable angles at which the object is seen. It is intuitively very simple when one passes an object which can only be seen in one direction, then it will be visualized from that side only. If, however, one can look forward and backward at the same object, the number of observables is much increased and captures more details of the underwater structures.

The above has been demonstrated by surveying close to the jacket area in u-bathymetry Phase 2 of this project.

9.1. Integration with the ROV.

The multidisciplinary sensor suite SpiDeR facilitates the integration operation due to simplistic mechanical and electrical interfacing. The mechanics are limited to fastening the mounting frame of the module onto the ROV frame and ballasting for weight. The electrical interfacing consists of a single cable which interfaces directly to the main multiplexer of the ROV. This time Matrix MK II from Innova technology was used. This multiplexer offers two Gb Ethernet connections one was used for the SpiDeR and one was used for the government instruments running two single beam echo sounder transducers. The multiplexer also provided timing pulse (PPS). The SpideR also triggered the acoustic transmission of the DVL attached to the INS system to avoid interference. The trigger signal is available at the same connection as power and data.

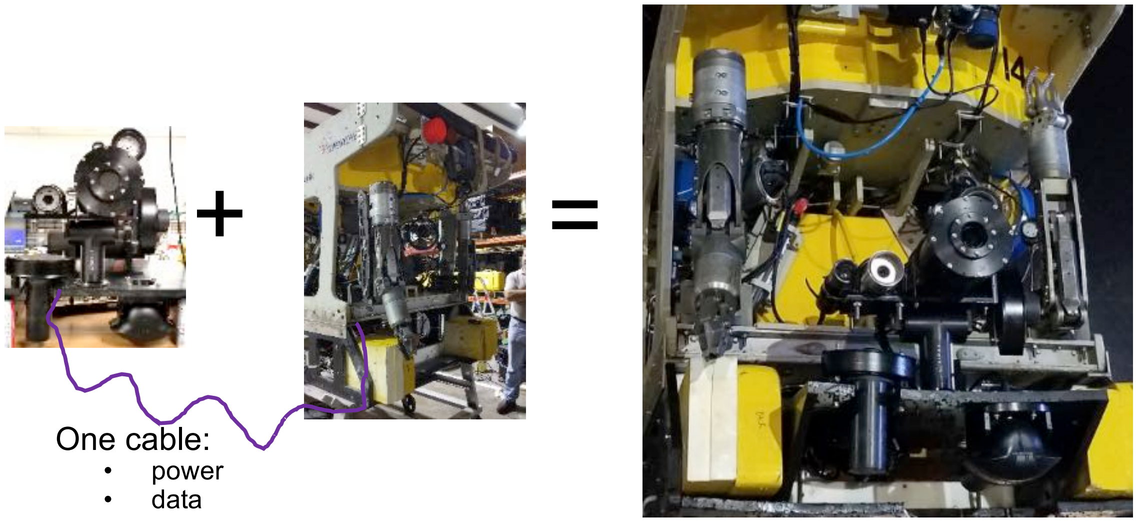

Fig. 4 SpiDeR integration onto ROV

The SpiDeR module was integrated in a short time and tested for operation in the test tank. Special care had to be taken to allow the bathymetry system to have unobstructed view through the ROV's base plate this was accomplished by cutting out a square in the plate, However, this limited the view of the down looking sonar to roughly 120deg. which was not a big problem for this application.

In addition, the ROV was also mobilized with ixBLue transponder Beacons and ixBLue ROVINS w/ RDI 1200Khz DVL System for navigation purposes. At this point also NOAA's acoustic equipment ES200 & ES333, were installed and ready for operation.

9.2. Testing in the test tank

Testing in the test tank comprises of buoyancy test and checking of all on board systems, such as propelling system, lights, cameras, powering of the devices and telemetry of the data over the fiber.

In the Fig. 5 below one can see the LIF laser beam bouncing off the water surface. It is interesting to zoom a little bit at the beam cross-section at the water surface to see some shining fluorescing particles of motor oil present in the test tank.

Fig. 5 ROV in the test tank (left), Lifting ROV off the test tank facility in Robert, LA (right)

After the test has been concluded the ROV was moved out of the tank by a crane and disassembled partially and got ready for the ground transportation to the Houma, Louisiana.

9.3. Integration of the ROV on the vessel

The vessel used for operation was a 170 ft x 36 ft DP1 mini- supply vessel M/V Gerry Bordelon built in 2011 with a gross tonnage just below 500 tons. The vessel offers accommodations for up 22 passengers and has a usable deck area of 110 ft. X 30 ft. The vessel comes with no infrastructure on the deck and all equipment needed to be secured on the deck before the trial could take place. The integration activity was planned for two days before the sea trial.

Fig. 6 M/V Gerry Bordelon - vessel for operation

The following ancillary equipment was mounted on the vessel in support of the operation

- External generators (2) min 100 kW and Power switch module
- Over the side USBL pole
- Air Compressor (Pole Deployment and Recovery)
- Survey Office Conex (10 ft X 8 ft)

Generators were mounted on the back deck to allow independent power for the survey and USBL operations, and facilitated redundancy in the event of power failure.

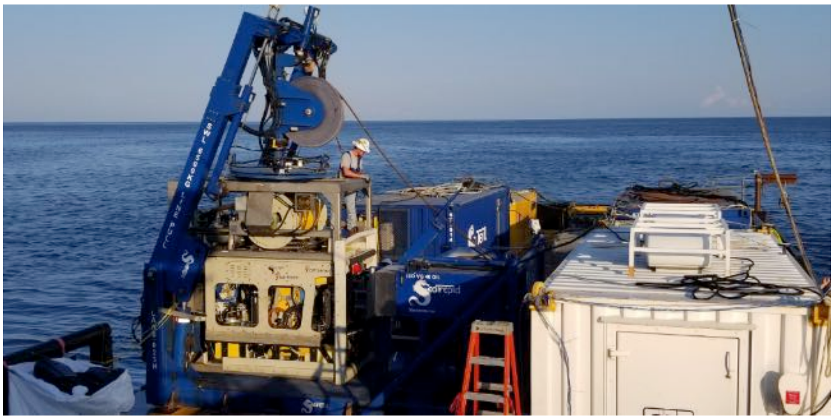

Fig. 7 ROV integration on the vessel

Additionally, the surface vessel was equipped with the following survey sensors:

- Navigation Computer with all required software and licenses
- Veripos LC5 Globally corrected GNSS system
- Hemisphere Vector V-series Heading sensor
- AML Sound Velocimiter
- GAPS iXBlue high-resolution USBL system with internal motion sensor

The offsets between the equipment and GNSS antennas were measured at this point. Similarly, the offsets aboard the ROV were determined.

10. Mission execution

10.1. Location of the survey site

The Mississippi Canyon 20 (28º55' N, 88º58'W) is located around 95 miles South-East of New Orleans. The transit took place on September 10th.

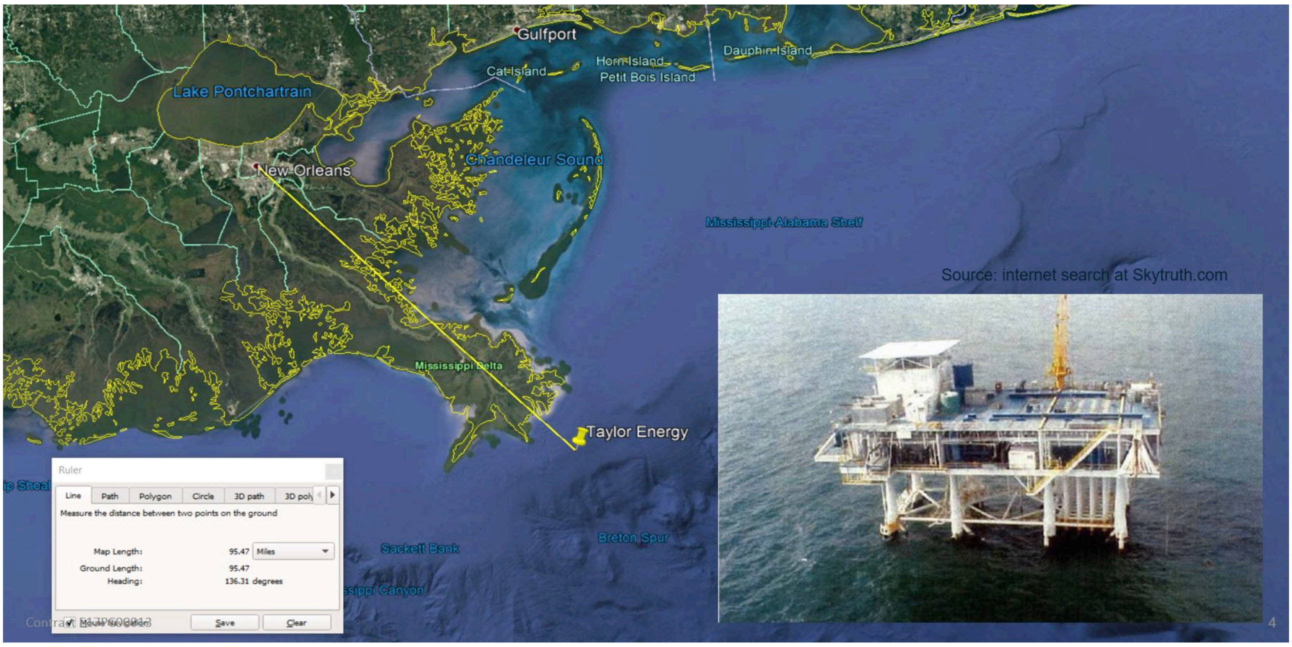

Fig. 8 The location of the survey site (Source: Google Earth) and historical photo before tower colapse.

When arrived at the destination the sheen of oil was present in the area, and the smell of gas could be easily observed.

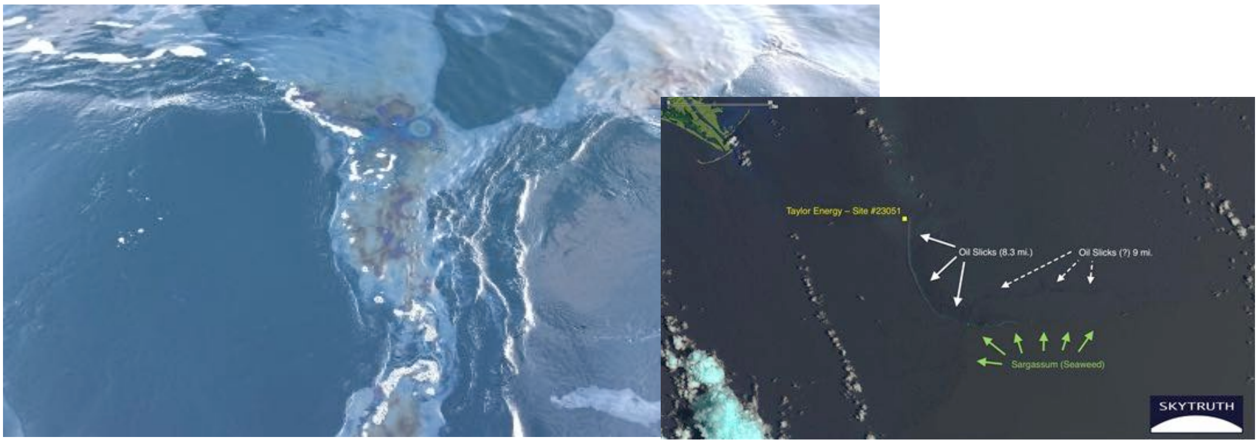

Fig. 9 The oil sheen visible in the area of interest (left).
Extend of the observed sheen on the right (source: FuelFix.com)

It is important at this point to understand what the true mission essence was about. The fact whether there is an oil leak or not wasn't the question of this mission. It has been known for the last decade that the leak of hydrocarbons is coming from the area of Mississippi Canyon 20. The real task at hand was to recognize the leak source and classify whether the leak coming from that source contain hydrocarbons and accurately document the source location and provide measurable evidence of its character.

11. Survey

As outlined by the requirement of the contract the survey was divided into three phases:

Phase 1 General Bathymetric Survey

Phase 2 Precision Bathymetric (u-Bathymetry) Survey

Phase 3 Source Recognition Survey

Each phase is discussed on successive paragraphs.

11.1. Speed of sound profiles

Every survey day began with a recording of the sound speed profile at or in close vicinity of the survey area. The data is presented in the graph below.

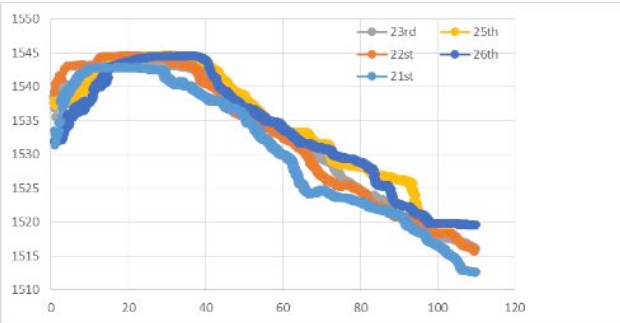

Fig. 10 The speed of sound profiles vs depth taken during the survey every morning.

The speed of sound profiles are used in both survey software and navigation system to compensate for refraction and improve the accuracy of the measurement.

12. Phase 1 Bathymetry survey

Before the general bathymetry survey starts, the ROV was prepared and checked for all subsystems.

The USBL system is visible in Fig. 11. The picture on the right-hand side shows the pole mount and several devices mounted on that pole.

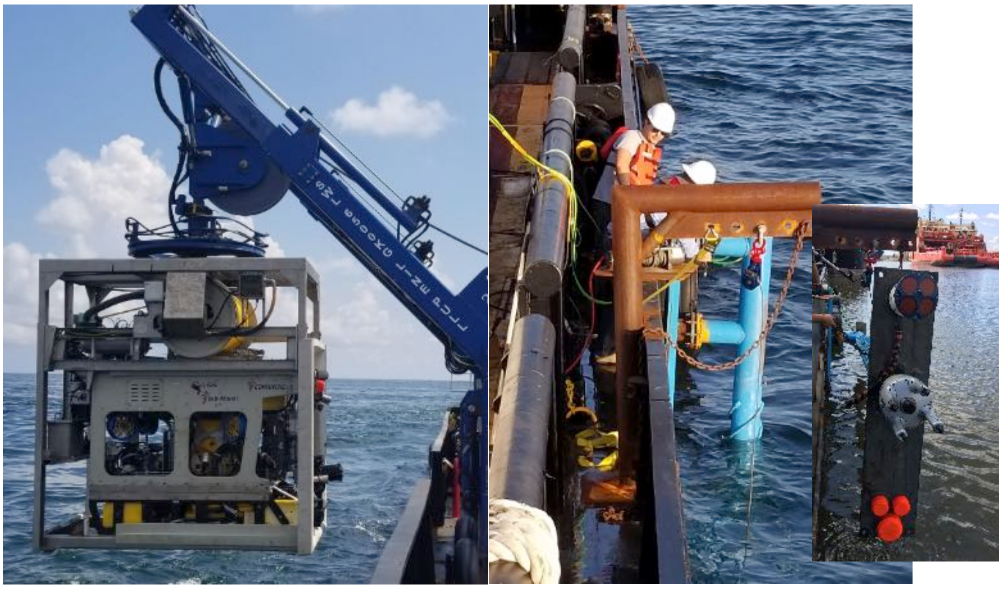

Fig. 11 ROV being launched from the starboard side (left), the USBL positioning system is mounted on the pole (right) with other equioment.

In the center part of the pole, the USBL system is mounted. It is the GAPS iXBlue high-resolution USBL system with internal motion sensor with the beacon being installed on the ROV side providing real-time transponder to the unit. Every time the speed of sound profile was taken it was also commanded to the USBL system to be used for improved accuracy.

There are also two other devices mounted on the pole, both being part of the NOAA operation. That is the ADCP (top) and single beam (bottom). The related work and analyses are not part of this report.

The general bathymetry was conducted from the ROV surveying between 50m-90m altitude using the bathymetry 3D mapping sonar. This was accomplished by running parallel lines until the area of interest was covered (Fig.12).

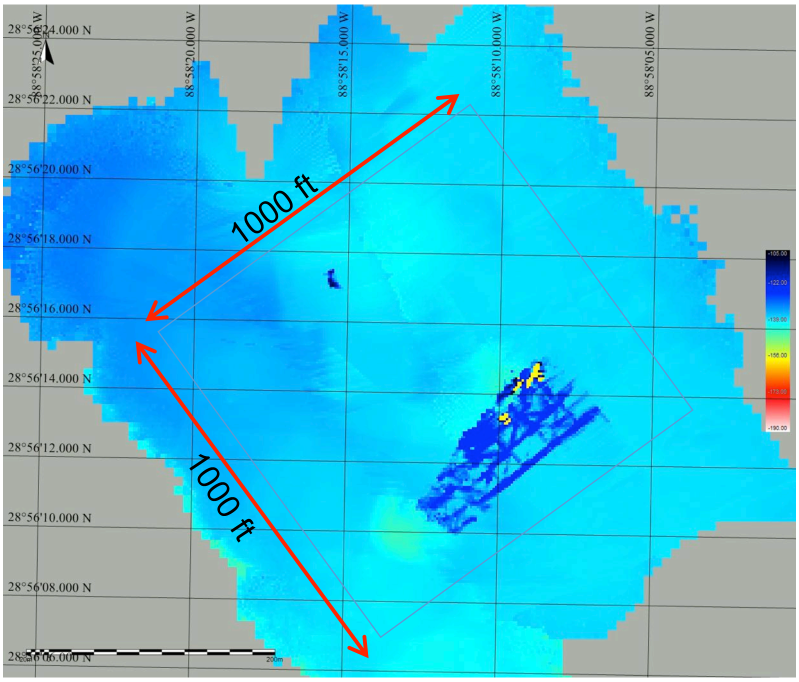

Fig. 12 The area of 1000 x 1000ft covering the location of the jacket and the original location.

Along with bathymetry acquisition, water column data was collected. Water column data allows suspended plumes to be observed as well as to detect any hazard in the water column (see Fig. 13). Real-time maps are generated while surveying allowing the surveyors to quickly assess the ensonified area. After the survey, post-processing will take place to clean the data and to identify the area(s) of interest (potential sheen source location(s)).

As indicated on the Fig. 13 (left) the main plume has been detected to extend from the bottom up to the surveying altitude, most likely proceeding up to the water surface. The plume grows in size and changes directions. Sometimes observed to reverse two times before reaching the top due to currents.

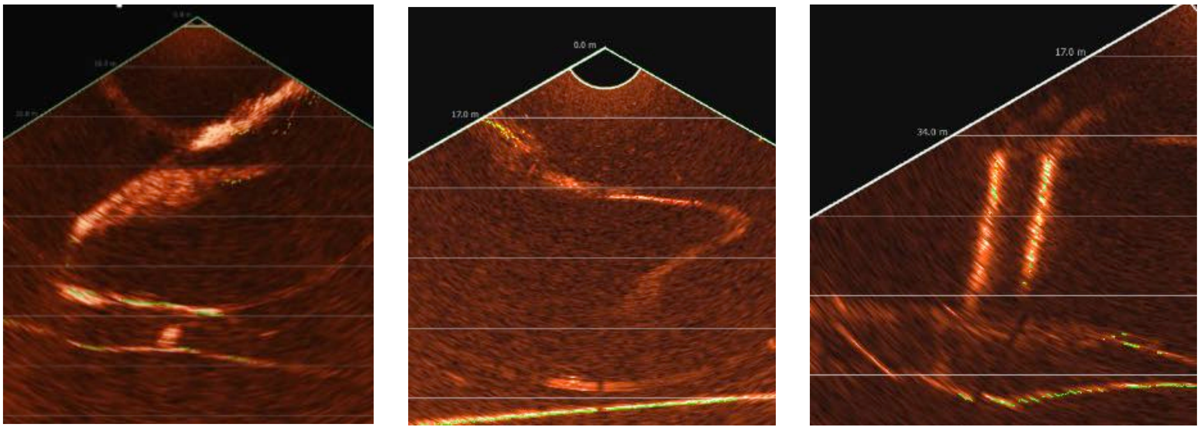

Fig. 13 Different captures of the main plume character

It could also be seen that the plume separates and more buoyant bubbles, having higher vertical speed, reach the surface while the less buoyant (perhaps dissolved hydrocarbons) separate and stay in the water column. Taking a different view at the plume from different angle (right-hand side of Fig. 13) it can be seen that there are actually two plumes, not one as initially believed. The exact location and recognition of the source will be done in Phase 2.

During the initial survey, it was also possible to see the hazard suspended roughly 35 m above the jacket (right-hand side of Fig. 14). Initially, it was not clear what this hazard was but then later using the forward looking sonars it was shown to be some sort of a structure attached to the jacket with metal rods (left two images in Fig. 14).

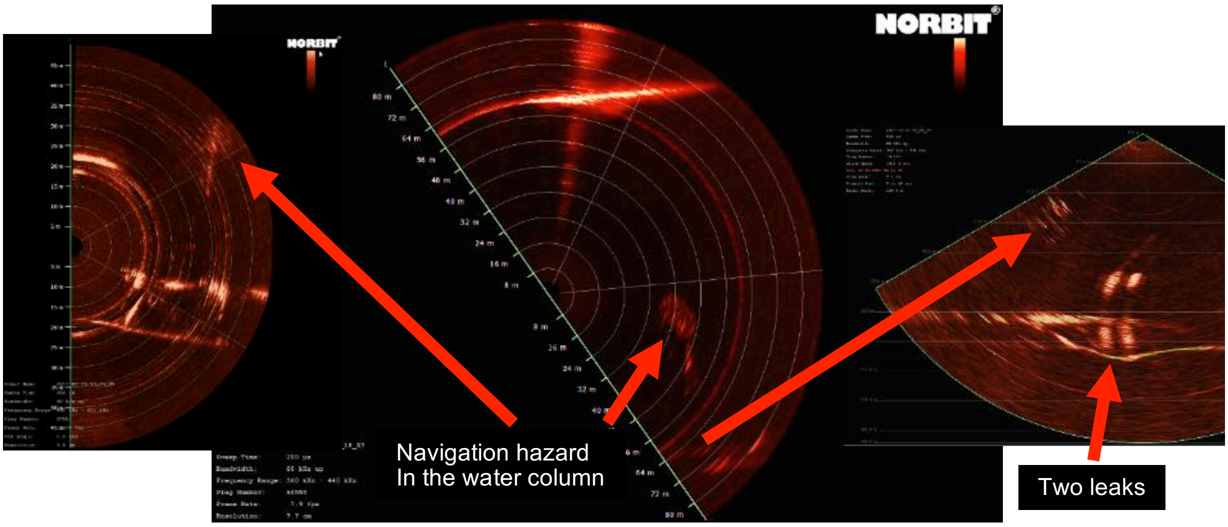

Fig. 14 Images showing the hazard located in the area of the main leak

The hazard is believed to be a collapsed collector dome structure left from the past. The remains are located at roughly 80m below the surface and do not pose a danger to general navigation, but it may cause trouble for any towed objects such as fishnets if they happen to be in that area.

12.1. General bathymetry survey results

During the data processing of Phase 1 it was possible to capture the scene from various survey lines and various directions. An instructive illustration of this phase effort is presented in the figure Fig. 15.

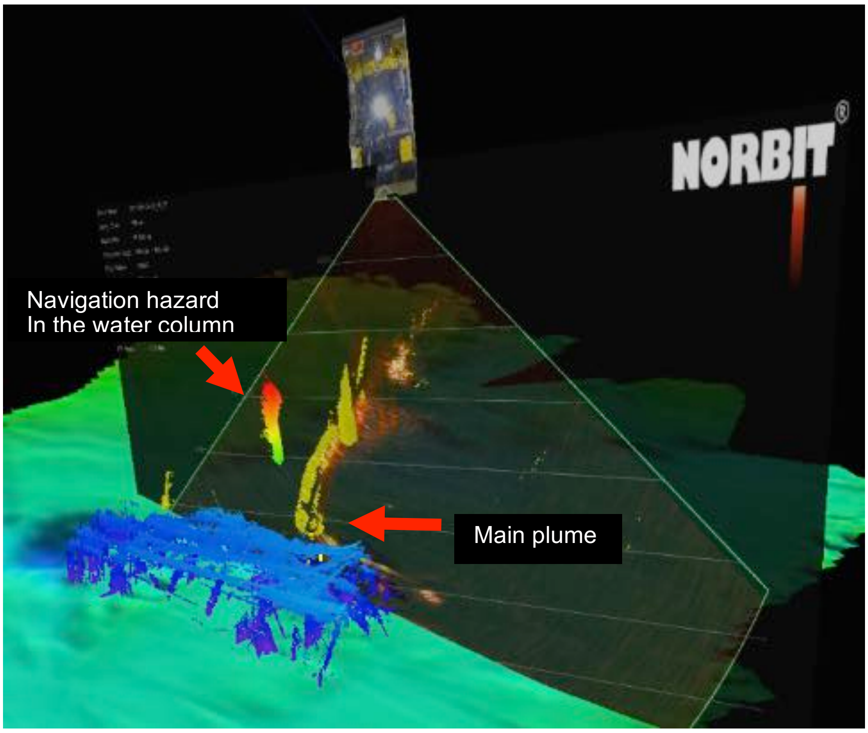

Fig. 15 The general bathymetry survey already reveled the plume character

During the processing, a couple of new leaks were found. However, they were smaller than the main leak. All findings are outlined in the figure Fig. 16. In total four potential leaks were located and one navigation hazard.

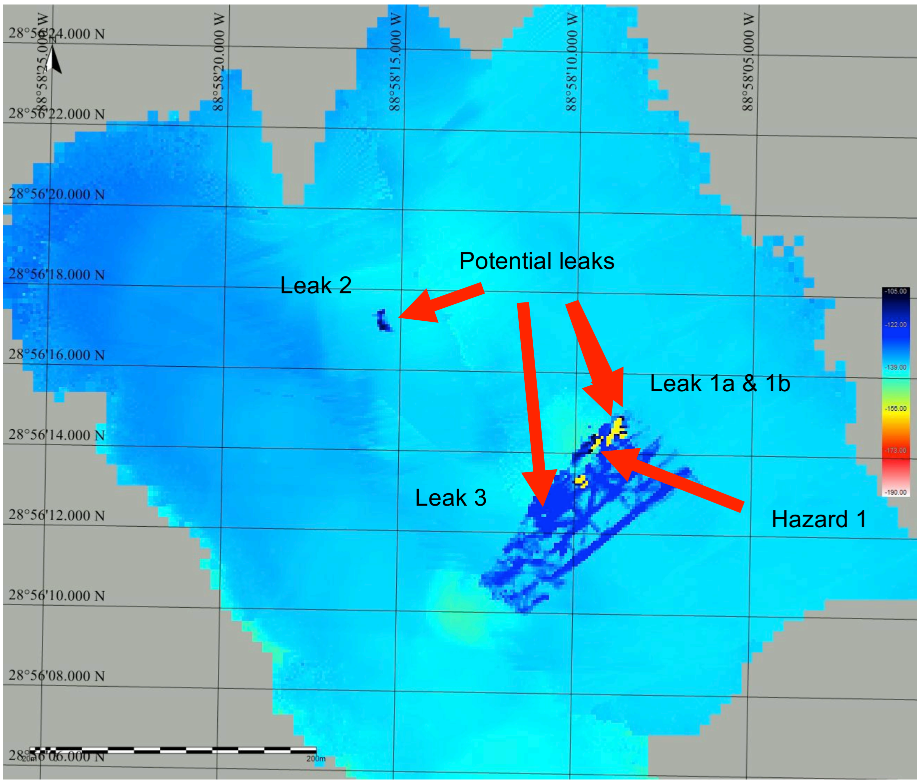

Fig. 16 Location of potential leaks in the area

The complete listing with the location is as follows:

Located (lat,lon) leaks locations:

- Leak 1a: 28° 56’ 14.24”N ; 88° 58’ 09.80”W
- Leak 1b: 28° 56’ 14.03”N ; 88° 58’ 10.00”W
- Leak 2: 28° 56’ 16.94”N ; 88° 58’ 15.23”W
- Leak 3: 28° 56’ 11.68”N ; 88° 58’ 11.51”W

Located hazards :

- Hazard 1:
  lat,lon: 28° 56’ 13.31”N ; 88° 58’ 09.80”W
  Depth: 80m
- Jacket center lat,lon: 28° 56’ 12.60”N ; 88° 58’ 09.70”W
  depth: 137m (bottom), 121m (top)

The leak depicted as Leak 2 which is located in the original installation angle of the jacket before the collapse is believed to be gas only. That has been confirmed by a previous study (not included in this report) performed by BSEE. The leak 3 was found to be a small leak compared to the main Leak 1(a&b) and it was requested by BSEE to continue the remaining portion of the investigation only for Leak 1a & 1b.

13. Phase 2 - u-Bathymetry survey

Once the general bathymetry was performed, and the hazards, as well as the main plume, was identified then the u-bathymetry phase was conducted. The u-bathymetry consisted of a high-resolution survey in the given locations where the leak was thought to originate. The detailed, high-resolution bathymetric survey requires the ROV to be operated at a lower altitude which has been determined to be roughly 20m above the seafloor. The bathymetry 3D mapping sonar will be used to collect bathymetry and water column data to map the exact location of the source and prepare for the classification phase.

A sample frame of the u-bathymetry is presented in Fig. 17 showing the complicated structure just below the ROV and two leaks on the left-hand side.

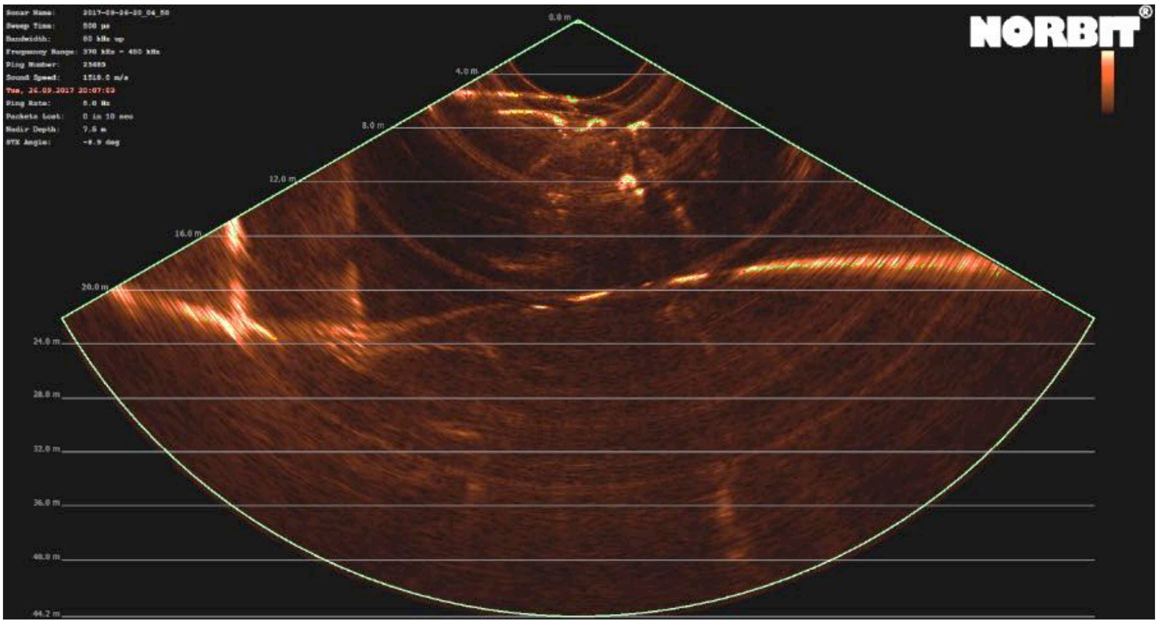

Fig. 17 The u-bathymetry snap shot using 3D scanning downloooking sonar.

The online processing was followed by onboard processing of the collected data and identification of the potential sheen source area(s). The result of the processing is presented in Fig. 18. The u-bathymetry aims to heavily oversample the space and statistically, average the false data to map the features with more details and with better coverage.

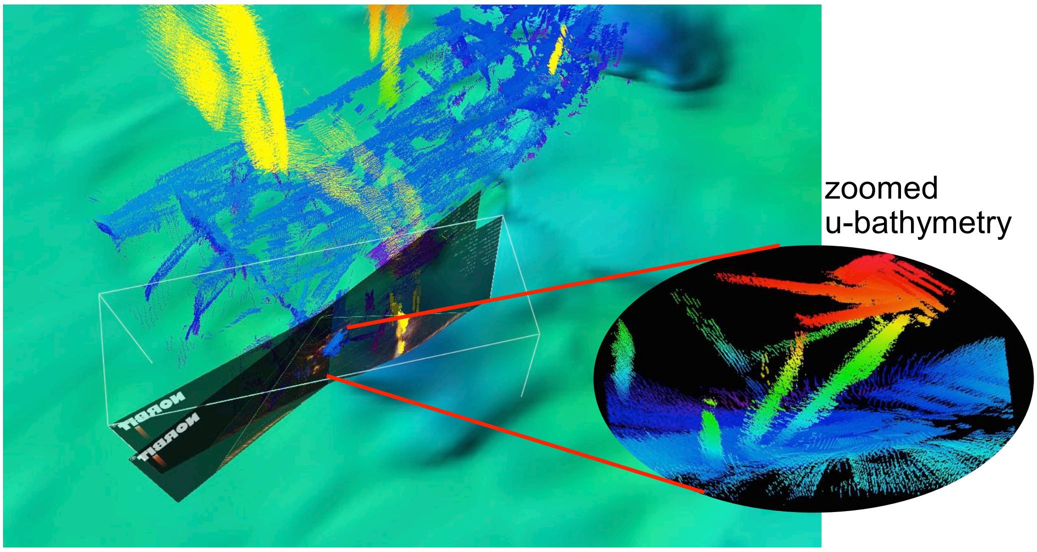

Fig. 18 The resulting point cloud of the u-bathymetry using 3D scanning downloooking sonar. Structure (jacket) is collored in blue. The leaks are colored in yellow.

As one can imagine a standard method of surveying of this type of environment results in many gaps behind the steel legs of the underwater structure as sound cannot penetrate hard objects. It may take many attempts to position the ROV at different angles to try to hit the target with different angles and sometimes it’s an impossible mission.

But when the STX sweeping capabilities are used, a single line covers all looking angles and allows a quick and efficient cover of the area without gaps and positioning errors.

For the visualization purposes, it is instructive to overlay the raster sonar image onto the digital point cloud to obtain the confidence in the detection scheme (Fig. 19).

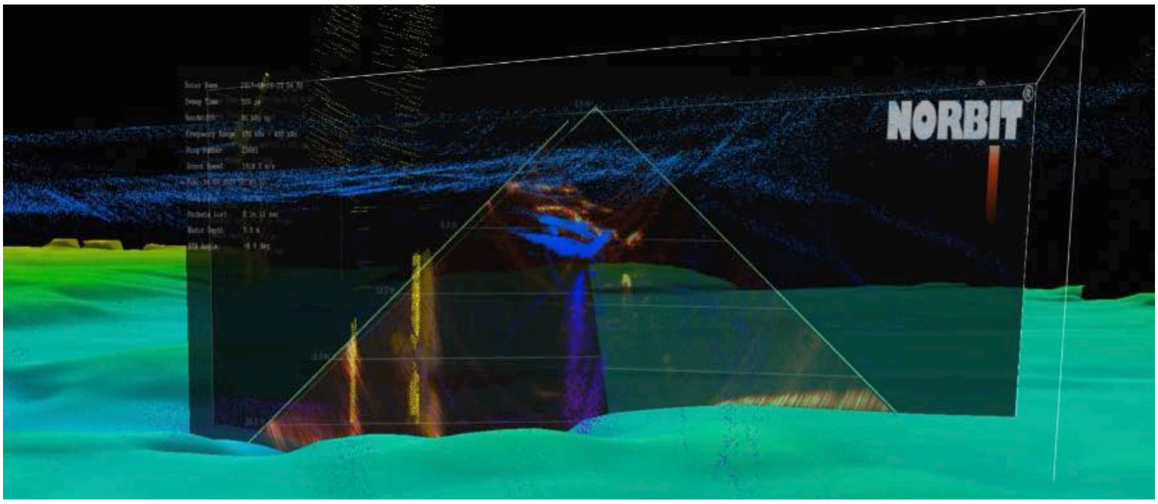

Fig. 19 The u-bathymetry using 3D scanning downloooking sonar with a single snap shot overlaied on the digial point cloud data. Structure (jacket) is collored in blue. The detected leaks are colored in yellow.

The result of u-bathymetry and Phases 1 & 2 is the exact location of the leaks and the visualization allowing decisions on the last phase of the plan – the recognition and classification phase 3.

14. Phase 3 - Recognition and classification

Once the Phase 1 and Phase 2 are done, the exact locations of the leaks are identified as well as any hazardous objects which need to be avoided. The chart in Fig. 16 showed the locations of the above. As before it was requested by BSEE to conduct the Phase 3 only for the main leak 1a & 1b as they were the main interest.

Leak source recognition consists of navigating the ROV in close vicinity of the areas of interest identified in the bathymetry surveys from previous days. The forward-looking 4D sonar and FLS sonar will now be used for acoustic sampling. The ROV operator has safely navigated to a proper location of the ROV to ensure best possible visibility of the source sites for the cameras and laser unit. The LIF (**L**aser **I**nduced **F**luorescence) detector unit has been used along with the video camera to classify the leak to contain the hydrocarbons.

Fig. 20 Image from ROV camera showing LIF beam (center) and lights (left) for video camera (right)

The LIF detector unit contains specialized optics which filters only the fluorescent response corresponding to the hydrocarbon emission. The device has been manufactured by partner Spectra Solutions and has been successfully used in the past to classify the hydrocarbon plumes. However, in order for the LIF detector to be able to operate it needs to be put in a close vicinity of the plume, so the laser light has a chance to reach it. The performance will greatly depend on the turbidity of the water and the closer one can get to the plume the better the chances for success. To navigate the ROV and LIF unit in the close vicinity of the plume the two forward-looking sonars were used.

To visualize the mutual relation of the vertical and horizontal sonar the following image is presented.

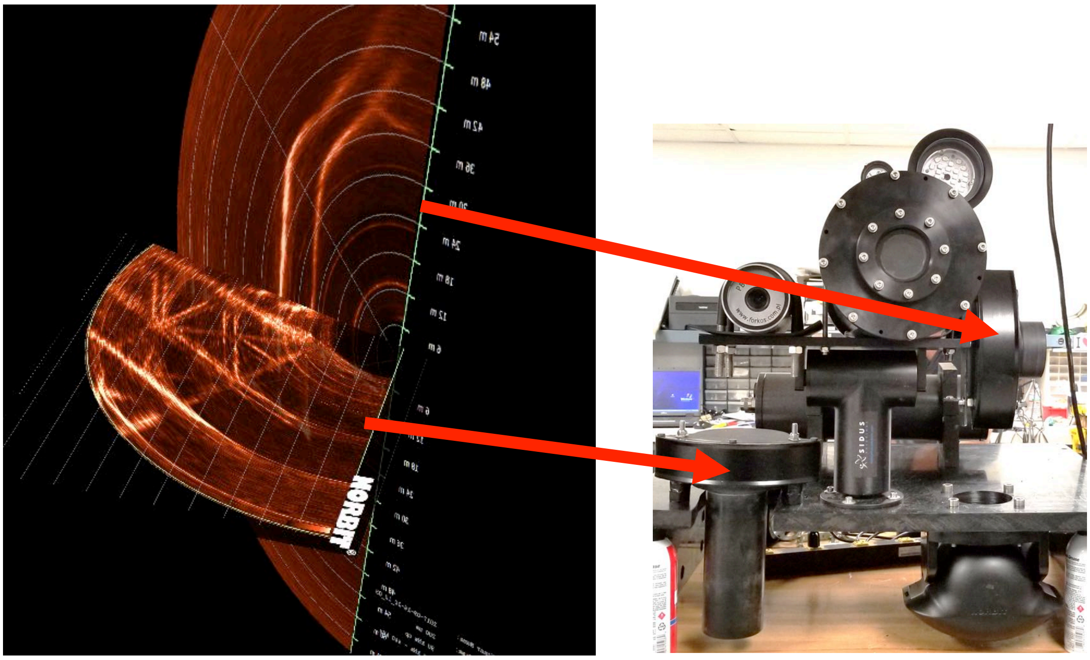

Fig. 21 Images from vertical and horizontal forward lookers give full picture

The combination of the two sonars has proven to be very efficient in navigating the ROV and visualizing the plume. With the horizontally looking sonar it was easy to instruct the ROV navigator to perform the ROV positioning in the required manner, and with the vertical sonar, it was possible to lower the ROV to the a safe altitude without the risk of hitting any objects.

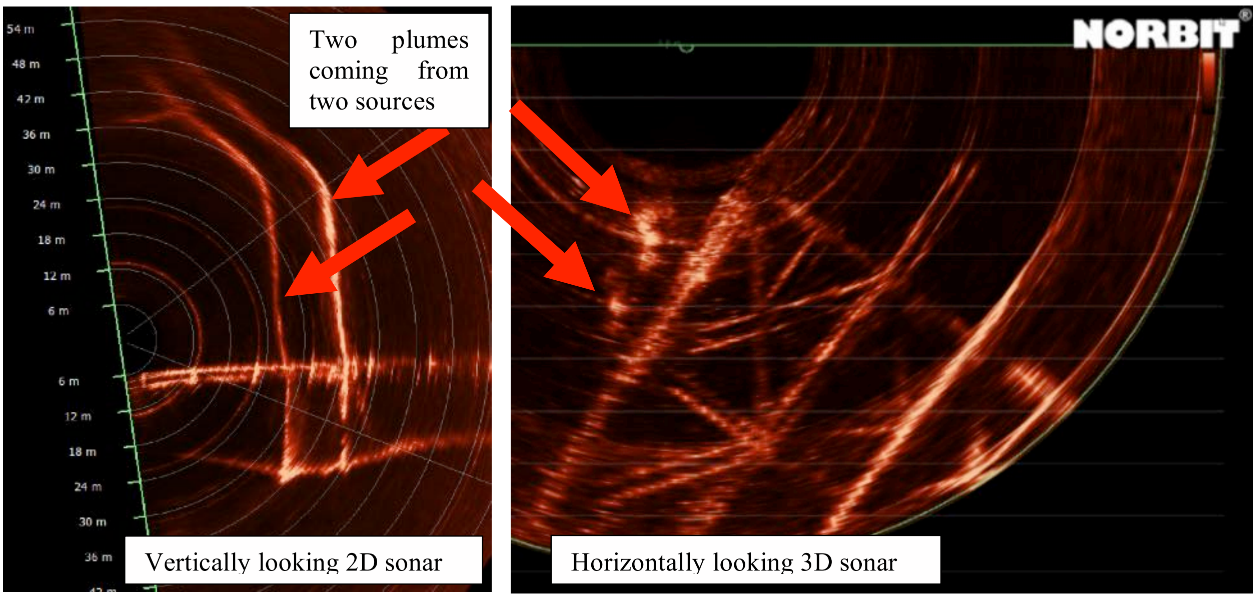

Fig. 22 Two plumes coming from two sources visible on vertical (left) 2D and horizontal (right) 3D-FLS sonar imagery

Superimposing the sonar single pings onto the grid model and the point cloud gives a good visual interpretation of the environment.

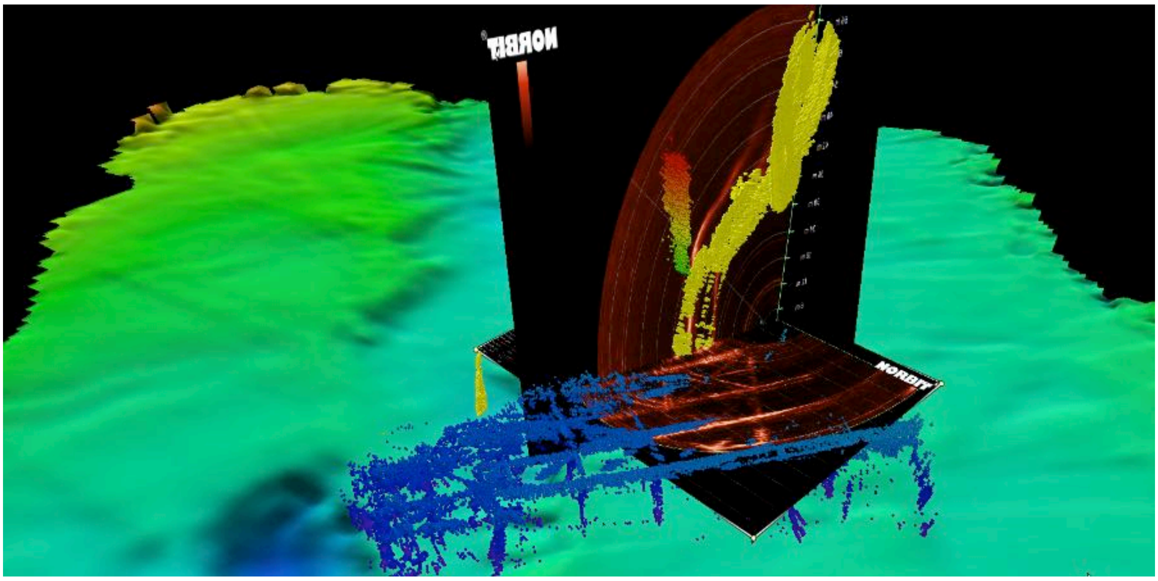

Fig. 23 Vertical and horizontal sonar images overlaid with the DTM and point cloud at the site.

With such presentation, it is possible to see the precise navigation needed to conduct a safe operation with the ROV. The horizontal sonar cuts the space in the horizontal plane, yet scanning the jacket up and down building its three-dimensional point cloud. When at the same time the vertically looking FLS sonar offers the full display of the entire scenery in the active sonar sector. Both of them give a complete picture of the situation developing in the dynamic underwater environment where the video cameras do not offer any aid due to low visibility.

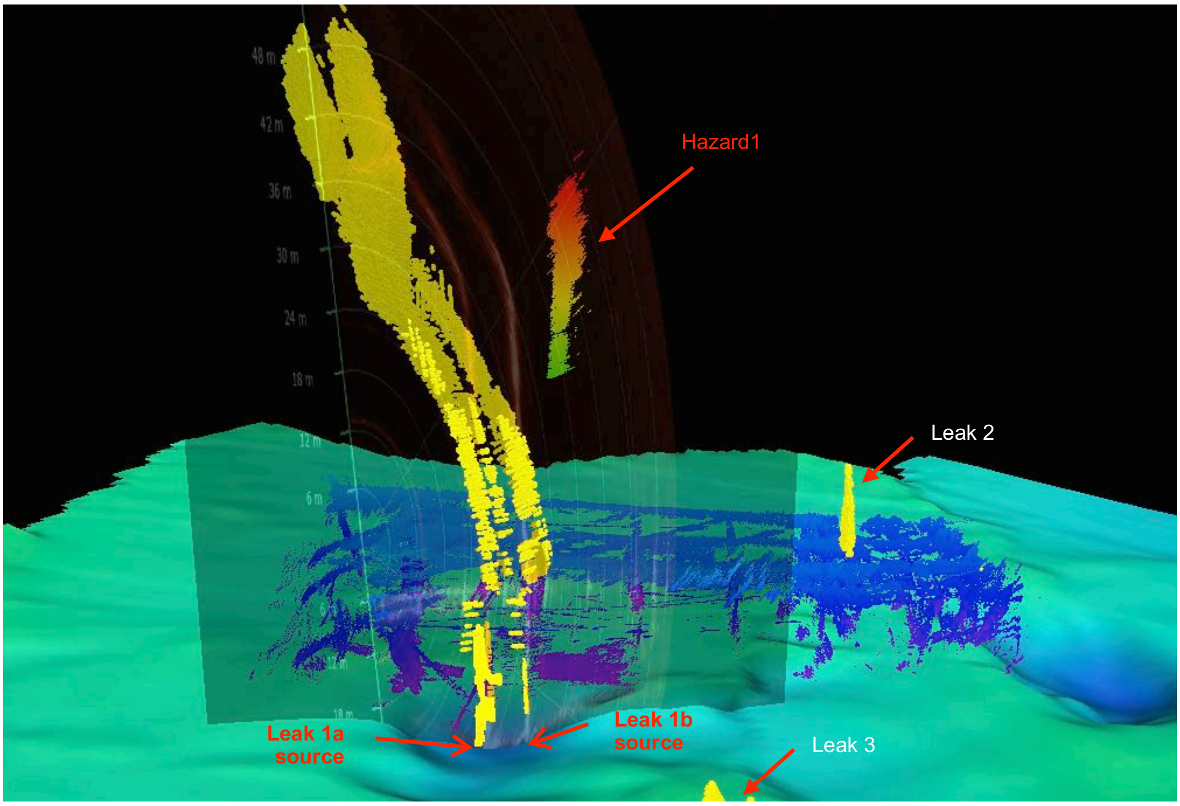

Fig. 24 Vertical and horizontal sonar images overlaid with the DTM and point cloud at the site.

The entire positioning procedure allowed positioning the ROV in a very close proximity of the plumes and entering the classification part of Phase 3 with the LIF detector.

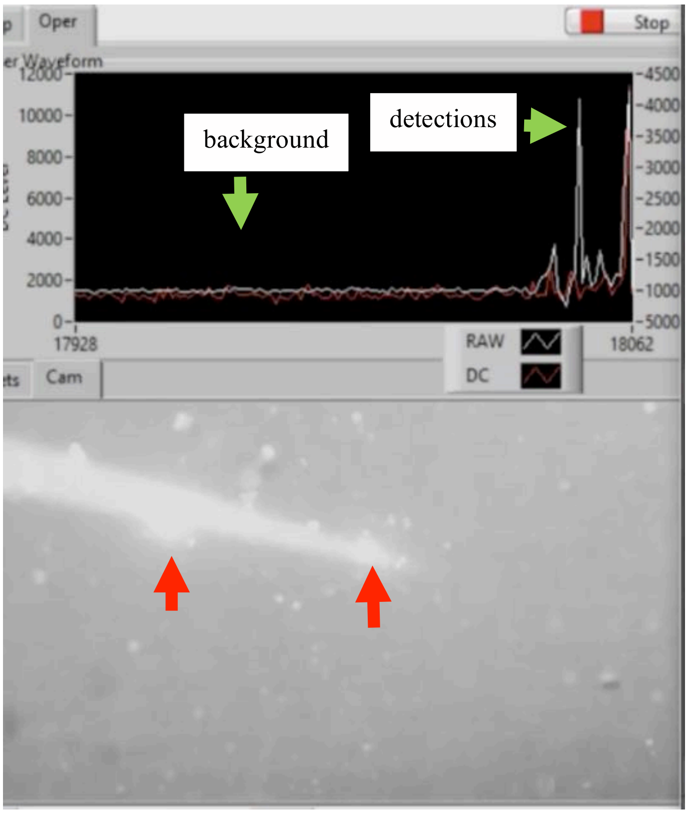

Fig. 25 LIF classification of the plume (top) and video camera (bottom) showing shining fluorescent particles passing by the laser beam

The LIF operates using laser light and as such is subject to the law of physics of optical light. That means its range will depend on the turbidity of the medium. However, provided it gets to the detection range, which in this case we found to be 2-4m, it offers unique classification capabilities by being able to distinguish between a gas leak and an oil leak.

In Fig. 25 one can see raw data coming from the LIF detector. The first part of the data was collected when the ROV was navigating toward the plume. Then by the end of the data plot, the laser cuts through the plume and finds the large content of hydrocarbons.

Further inspection of the video camera also confirms the shining fluorescent objects passing by the laser beam. These are the oil drops which contribute to the large spikes on the laser display. The general increase in the background of the LIF readings is attributed to the increased content of dissolved hydrocarbons in the plume.

After the leak was recognized oil sampling was completed using 4 Niskin bottles, see Fig. 26.

Fig. 26 Oil samples collection using Niskin bottle and robotic arms to release the lock-in mechanism.

With the help of the FLS sonars (as before) the bottles have been positioned as close to the source as possible to capture samples of the oil. The bottles were closed using the robotic arms on the ROV and securely delivered to US Coast Guard personnel after returning to the surface.

The samples were analyzed by Marine Safety Laboratory report MSL Case Report 18-002. The analysis contained Gas Chromatography and Gas Chromatography-Mass Spectrometry methods. Collected sampled were found to contain volatile compounds, crude oil, and petroleum hydrocarbons (full report can be found at the end of this report).

15. Deliverables

The deliverables covered in this report contain the following items:

a) The integration report with the photos and description of the integration of SpiDeR at the ROV.

b) The complete set of raw data used for all analysis during and after the sea trial. That will include raw bathy data, FLS data, META data from leakage detection and laser data, as well as the processed data for the above.

c) The video footage and the photos taken during the testing period.

d) The analysis of the surveyed area with digital charts and models of the sea bed. That will include phase 1 and phase 2 analysis with high resolution bathymetry and leakage analysis.

e) The full report outlining the entire operation, data collection, analysis and results.

f) The PowerPoint presentation highlighting the above deliverables and operation.

16. Conclusions

The BSEE contract E17PC00013 has been executed according to the requirements, and this report outlines the findings required by the contract.

The report outlines the use of the Spill Detection and Recognition module SpiDeR integrated on the ROV used for the operation.

The location of the leak of interest along with recognition of the source and classification of the leak was successfully performed and it was shown that the leak contained petroleum hydrocarbons in the close vicinity of the jacket at the location outlined earlier in this report.

17. Appendix 1 - MSL Case Report 18-002.pdf

Here is the reprint from the Oil sample analysis report MSL Case Report 18-002.pdf referred in this document.

Oil Sample Analysis Report

Bureau of Safety and Environmental Enforcement
Case Number

Marine Safety Laboratory
Case Number 18-002

UNITED STATES COAST GUARD
MARINE SAFETY LABORATORY

U.S. Department of
Homeland Security

United States
Coast Guard

Manager
U.S. Coast Guard
Marine Safety Laboratory

1 Chelsea Street
New London, CT 06320
Phone: (860) 271-2704
Fax: (860) 271-2641

16450
03 Oct 2017

Attn: Mr. David Fish
1849 C St NW
Room 5429, MS 5438
Washington, DC 20240

Dear Mr. David Fish:

The laboratory analysis of this case has been completed and our report is forwarded. The technical data supporting the report (spectrograms and chromatograms) have been archived at our facility and are available upon request. We will maintain the oil samples in refrigerated storage pending final case disposition.

Questions concerning this report or the analytical methods used should be directed to the Supervisor of Analysis.

K. JUAIRE

Encl: (1) MSL Report 18-002

United States Coast Guard
Marine Safety Laboratory
Oil Sample Analysis Report
18-002

Requestor: Bureau of Safety and Environmental Enforcement
Unit Case/Activity Number:
Received: 02-Oct-17 **Via:** Federal Express 8119 3750 6220

Number Of Samples: 10
Lab ID for Spills: 1, 2, 3, 4, 5, 6, 7, 8, and 9
Lab ID for Sources: n/a
Lab ID for Background: 10

Analysis Methods:

- ☑ GAS CHROMATOGRAPHY (GC)
- ☑ GAS CHROMATOGRAPHY-MASS SPECTROMETRY (GC-MS)
- ☐ INFRARED SPECTROSCOPY (IR)

Laboratory's Conclusion (as explained below): ID ONLY

RESULTS:

1. Samples 18-002-1, 2, 3, 4, 5, 6, 7, 8, and 9 were specified to be representative of spilled oil. Analysis indicates:
   A. Samples 18-002-1, 2, 3, 4, 5, 6, and 7 contain moderately weathered crude oil. Non-petroleum contamination is present in samples 18-002-1, 4, 5, 6, and 7. The weathering assessment is derived from the relative absence of a "typical" n-alkane profile; volatile compounds are still present. Samples 18-002-4, 5, 6, and 7 are more weathered than samples 18-002-1, 2, and 3.
   B. Sample 18-002-8 contains petroleum hydrocarbons. The quantity is not sufficient to determine the type of petroleum oil present based on the analysis conducted.
   C. Sample 18-002-9 does not contain a quantity of petroleum oil detectable by the analysis conducted.

2. Sample 18-002-10 was specified to represent a clean Teflon pad. No petroleum oil was detected.

CONCLUSIONS:

1. Samples 18-002-1, 2, 3, 4, 5, 6, and 7 contain crude oil.

2. Sample 18-002-8 contains petroleum oil. The quantity present is not sufficient for conclusive product identification.

3. Sample 18-002-9 does not contain a quantity of petroleum oil detectable by the analysis conducted.

4. Sample 18-002-10 contains an essentially oil-free Teflon pad.

SUPERVISOR OF ANALYSIS K. JUAIRE [signature] **DATE** 03-Oct-17

United States Coast Guard
Marine Safety Laboratory

Oil Spill Identification Analysis
Cost Recovery Documentation

Laboratory Case Number:	18-002
Requestor:	Bureau of Safety and Environmental Enf
Unit Case Number:	
Number of Samples:	12
Cost Per Sample Prepared:	$20.00
Total Costs of Sample Preparation:	$240.00
Number of Analyses:	26
Cost Per Sample Analyzed:	$86.00
Total Costs for Analysis:	$2,236.00
TOTAL COSTS:	$2,476.00

This documentation is provided for purposes of Phase IV - Documentation and Cost Recovery under the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR Part 300)

Signature: Kristy Juaire **Date:** 03 Oct 2017

United States Coast Guard
Marine Safety Laboratory Sample
Check-In Log

MSL Case/Activity Number: 18-002

Requestor: Bureau of Safety and Environmental En **Unit Case Number:**

Federal Project Number: **Delivery Method:** Federal Express

Received Date: 02 Oct 17 **Delivery Number:** 8119 3750 6220

Priority: Yes **Rush:** No **Comparison:** No

Lab ID 18-002	Sample Descriptions from Sample Jars		Spill	Source
1	001	TEFLON PAD SWIPE OF ROV, PORT SIDE 26 SEP 17 1805	☑	☐
2	002	TEFLON PAD SWIPE OF ROV, FRONT AND STARBOARD SIDE 26 SEP 17 1808	☑	☐
3	003	TEFLON PAD SWIPE OF ROV AFTER SAMPLE COLLECTION 26SEP17 1943	☑	☐
4	004	NISKIN BOTTLE #1 TEFLON PAD 26 SEP 17 2045	☑	☐
5	005	NISKIN BOTTLE #2 TEFLON PAD 26 SEP 17 2050	☑	☐
6	006	NISKIN BOTTLE #3 TEFLON PAD 26 SEP 17 2055	☑	☐
7	007	NISKIN BOTTLE #4 TEFLON PAD 26 SEP 17 2101	☑	☐
8	008	SEA WATER FROM TOP OF NISKIN BOTTLE 26 SEP 17 2105	☑	☐
9	009	SEA WATER FROM BOTTOM OF NISKIN BOTTLE 26 SEP 17 2108	☑	☐
10	010	CLEAN TEFLON PAD 26 SEP 17 2110	☑	☐

Remarks: ID only. Sample 10 designated as "Spill" for comparison purposes only.

Samples checked in by: MST3 CRYSTINA SCOTT *Crystina Scott* **Date:** 02 Oct 17

Sample Custodian: MST2 CHELSEA WARREN *[signature]* **Date:** 03Oct17

Supervisor of Analysis: K. JUAIRE *Kristy Juaire* **Date:** 03 Oct 17