# UNDERWATER INSPECTION AND MAINTENANCE PROGRAMS WITHIN NUCLEAR AND NON-NUCLEAR RELATED OPERATING SYSTEMS

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***Abstract***

The increasing age of the nuclear and non-nuclear power generating facilities requires extended inspection, repair and maintenance (IRM) activities to prolong the operation of these facilities past their original design life.

Commercial divers are often utilized to perform critical work at nuclear power plants, fuel reprocessing plants, waste storage facilities, and research institutions. These various tasks include inspection, welding, mechanical modifications and repairs, coating applications, and work associated with plant decommissioning. Programs may take place in areas such as the reactor vessel, equipment pool, spent fuel pool, and suppression chamber using manned intervention and remotely operated vehicles.

Some of these tasks can also be conducted using remotely operated vehicles (ROV's). Although specialist robots are not uncommon to the nuclear industry, the use of free-swimming vehicle's and remote systems for the inspection of underwater assets has increased due to improvements of the supporting technologies and information requirements needed to extend the life of these facilities.

This paper will provide an overview of the procedures and equipment necessary to perform unique work tasks using manned and unmanned techniques.

## INTRODUCTION

As nuclear power plants age, the condition of the structures, systems, and components (SSCs) affect the ability of the plant to operate safely and efficiently. Experience is now showing that plants can continue to operate well beyond their original design life if adequate inspection, repair and maintenance programs are initiated to deal with the degradation in infrastructure or to bring it up to current standards.

Continued safe and cost-effective operation requires that in-service inspections be conducted in accurate, repeatable, and commercially advantageous ways. At the heart of the inspection process lie a variety of non-destructive examination techniques for localized inspections and other methods that can be applied for the larger scale inspection of tunnels, intake and discharge structures.

Water is an integral part of a nuclear power facility. In addition to the conventional aspects of cooling and steam generation, it provides significant shielding of radioactive sources in holding and cooling ponds and spent fuel bays. Due to structural, operational, environmental, or radiation issues, it is frequently impossible to gain access to the water intake, transfer and discharge conduits or shielding facilities by dewatering. In such cases, inspection and intervention must be performed by specially trained and equipped commercial divers or remotely operated equipment.

This paper illustrates how diving in nuclear facilities brings the practices of commercial diving into areas where there is the potential for exposure to radiation and expands upon them to make this a safe and efficient means of intervention. While specialized robotic vehicles and systems are frequently used for the inspection of high radiation areas, this paper will deal with their uses for areas outside the radiation zones where access is not possible for manned intervention or it is economically more feasible to conduct the inspection robotically.

## UNDERWATER INSPECTION

### *COMMERCIAL DIVING*

Water provides excellent shielding from radiological hazards. By leaving the water in place, manned diving operations can frequently be conducted more economically than by de-watering, rendering the area safe and conducting the work in the dry. Specialized commercial diving procedures have been used in the US and other international nuclear facilities for more than 20 years. With the evolution of support technologies, it has proven to be a safe and effective method of getting the specialist diver to the worksite.

Well-established methods are in place for conducting diving operations in confined spaces, areas that require long penetrations and contaminated environments (biological, chemical and thermal hazards). Although commonly undertaken, these operations are never considered to be “routine”; proper planning and preparation is essential to make them safe for the diver and the facility with the same intent as the nuclear industry ALARA (as low as reasonably achievable) goals with respect to risk. Diving equipment, procedures and knowledge used in these environments are leveraged and expanded upon for the unique aspects of in-water work at nuclear plants.

As with any work program, it is essential to identify risks so they can be removed or mitigated to an acceptable level. For a nuclear dive, a thorough pre-dive survey must be conducted to determine the location of any “hot spots” - specific localized areas where radioactive material may have accumulated or been deposited. If the material cannot be removed and is in a location that poses an unacceptable risk to the diver, isolation blankets should be deployed to cover these areas to reduce the potential exposure.

Work procedures are then developed to ensure the diver avoids close proximity to or contact with any remaining areas.

In any contamination dive, the diver must be isolated from the environment. This is accomplished by the use of surface-supplied diving equipment that fully encapsulates and isolates the diver. The outer suit is made of heavy vulcanized rubber (*Figure 1*) and is inherently water proof, covering the feet, limbs, and trunk of the body. The hands are kept dry by attaching double-layered gloves to the arms of the suit with a dual watertight seal.

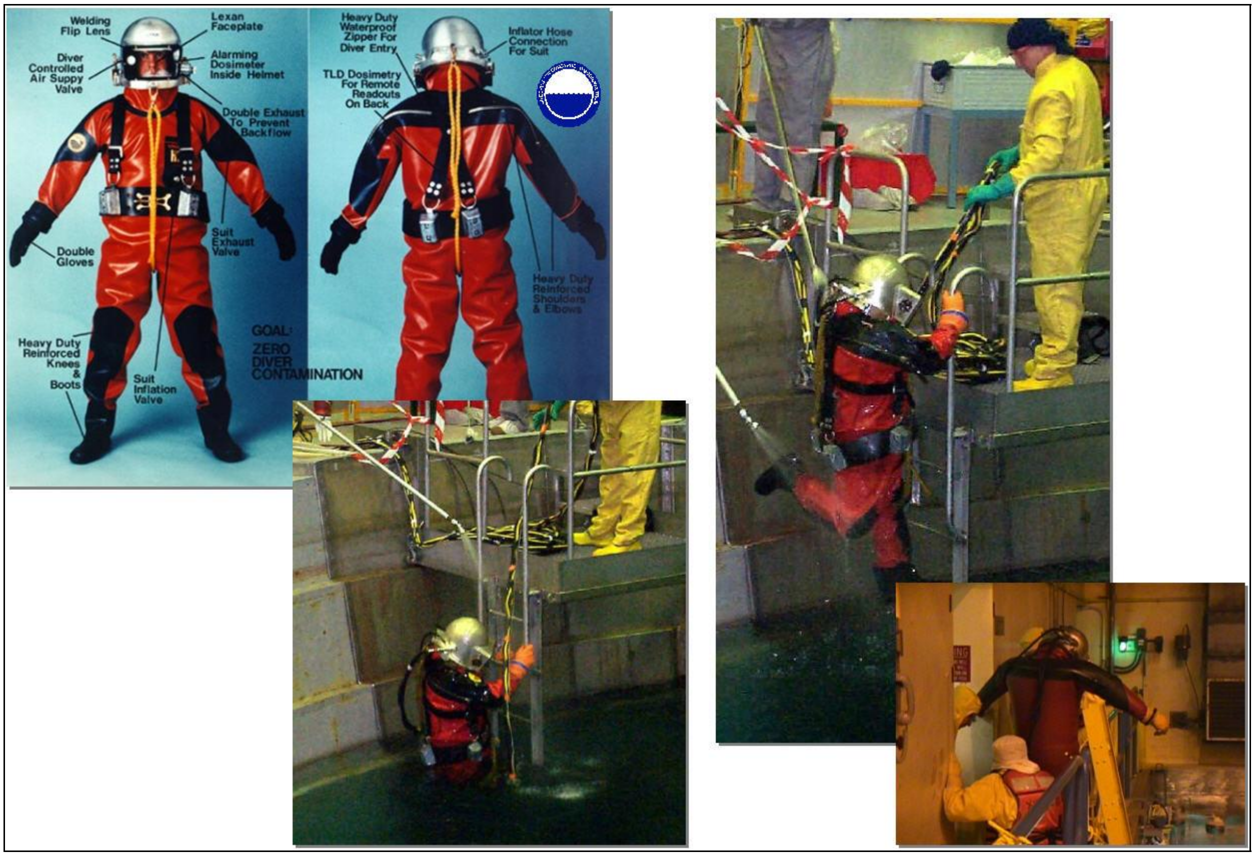



**Figure 1: Upper left: typical dive suit and helmet configuration; Center & Upper right: Wash-down as diver enters and exits; Lower right: Drying diver before removing suit**

The diver's helmet is connected to the neck of the suit with a rubber O-ring seal. The helmets used are a constant-supply style where air is continually delivered to the helmet rather than through an oral nasal system that only delivers air on demand. By using a constant air supply, there is typically a slight over-pressure in the helmet. Should there be any minute leaks in a seal, air will migrate out of the helmet rather than allow water to leak in.

Another common risk associated with contamination dives is the potential for hyperthermia when working in elevated water temperatures. Cooling vests can be worn directly by the diver underneath the dry suit. These are either self contained closed circuit units that typically use ice for the cooling source or systems that use a chiller (or cool tap water) to circulate water through a series of hoses sewn into a vest or full undergarment.

When the diver returns to the surface, they are washed down to remove any residual contaminants.

Support personnel typically wear disposable, waterproof coveralls and boot covers, rubber gloves and face shields. The final wash-down and drying of the dive gear is done in a containment bin prior to removal of the diving helmet, gloves and suit.

This equipment and procedures for diving in contaminated environments require supplementation for nuclear diving with its added risk of radiation exposure. Thermo-Luminescent Dosimeters (TLDs) and/or Electronic Dosimeters (EDs) are worn under the dry suit to monitor the extremities, trunk, and head. Since the water in which the divers are working is such an efficient barrier, the dosage gradient is very steep between the diver and a radiation source. Adjusting the diver's position or orientation relevant to the source can often make a dramatic change in the exposure that the diver receives. For this reason, the ability to track the diver's exposure in real-time provides significant benefits over checking TLD badges after-the-fact. Systems such as the one shown in *Figure 2* can be worn by the diver and simultaneously monitored by surface personnel. Any increase in exposure can be immediately detected and the diver removed from the area.

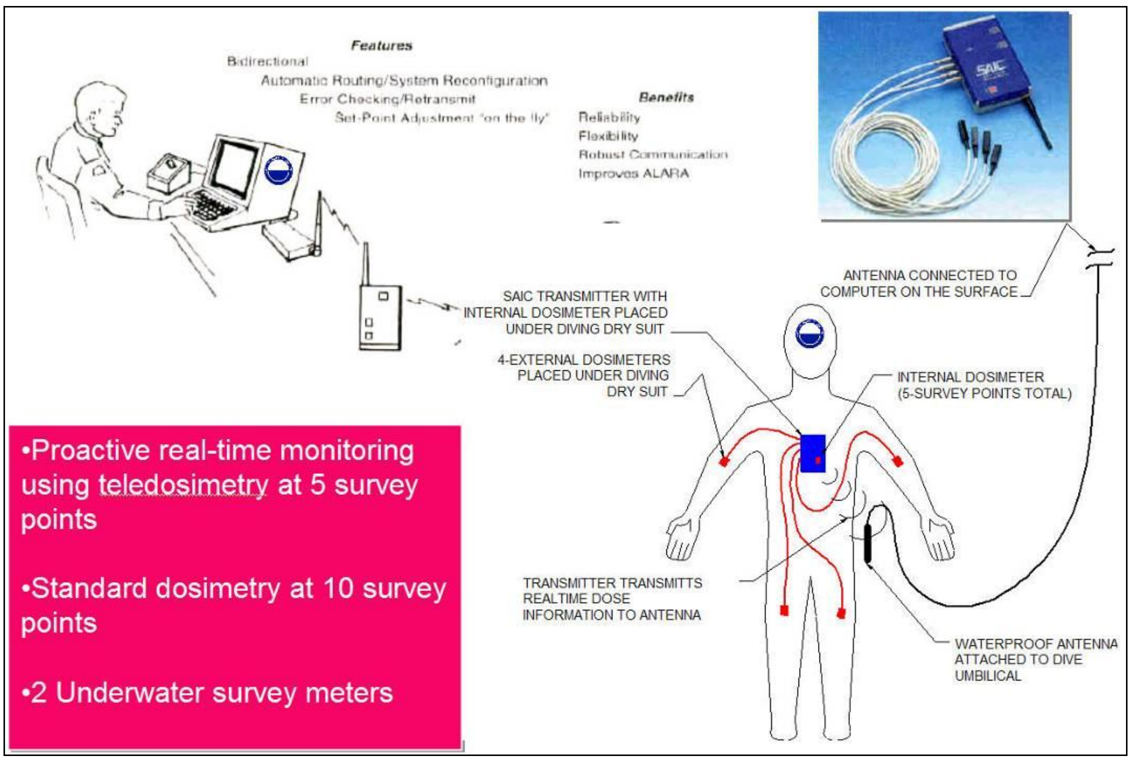



**Figure 2: System used for real-time dose monitoring. Dosimeters are placed in multiple locations on the diver.**

In summary, specially trained divers using the appropriate equipment and procedures can conduct many nuclear maintenance tasks faster and with less exposure than workers performing the same tasks in the dry. Sometimes, as in the case of dives on reactor internals or in the vessel itself, the work simply could not take place in a dewatered condition. This is generally due to the shielding effect of the water itself which is already in place. Although nuclear diving is sometimes perceived as a high-risk alternative to drain-down, it can be conducted quite safely from a human factors standpoint. A properly trained and experienced dive crew should be able to safely perform virtually any task that can be performed by topside personnel.

## REMOTELY OPERATED VEHICLES (ROV)

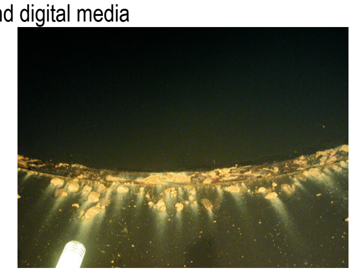
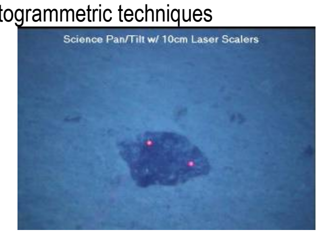
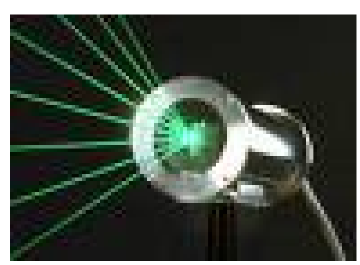
An underwater remotely operated vehicle (ROV) is an unmanned robot that can be sent underwater to conduct work while being controlled from the surface. The ROV generally has cameras and other sensors that are used to collect and transmit data in real-time through a control cable or umbilical to personnel at the surface.

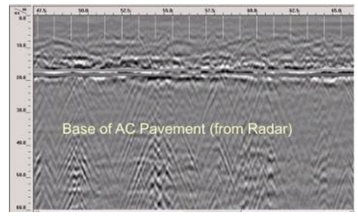
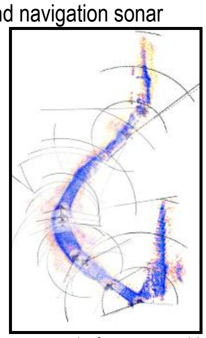
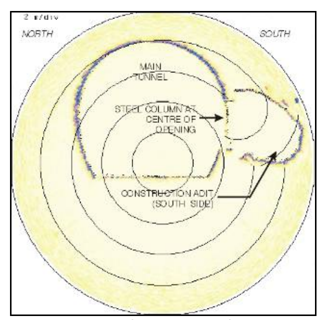
With the advancements in remotely operated vehicles (ROV’s) and the integration of specialized inspection techniques, it is now possible to conduct internal inspections of flooded tunnels and pipes up to 10 km from a single access point. Most of the benefits derived from a remote inspection are based on not having to dewater the system and being able to conduct an inspection from the safety and comfort of an area arranged for the equipment control consoles and data collection station.

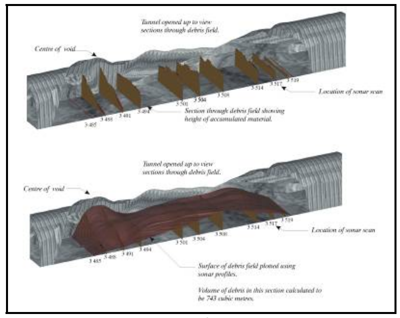
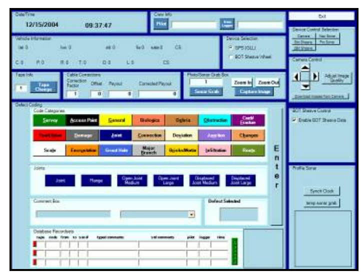
ROV's can be equipped with a wide variety of sensors, in addition to standard video cameras. These include high resolution sonar, ultrasonic thickness measurement devices, laser scaling systems, flow meters for leak detection, and magnetic flux instruments for metal pipe inspections. The application of fibre-optic technology to robotic systems significantly increases the type and number of sensory instruments that can be integrated to ROV's. Fibre-optic systems are also virtually immune to electronic interference, permitting clear video signals to be transmitted over long lengths of cable without degradation of the signal. With all of the options available, many inspection goals can be met by using an appropriate ROV in a cost-effective and safe manner.

Most equipment that can be deployed by a diver can also be integrated to an ROV, with varying degrees of efficacy. If a technique normally requires a high level of dexterity, it will need significant modification in order to integrate it to the ROV. Table 1 lists some of the more common inspection requirements and techniques that have been conducted both by divers and ROVs.

**Table 1: Inspection requirements and applicable techniques.**

| *Requirement* | *Technique/Equipment* | *Sensor/Applications* |
|---|---|---|
| Conduct visual observations and document findings | Video camera, still camera, video recorders and digital media  *Joint in steel roll-out section of tunnel* |  *Downstream end of walkway in tunnel at rock trap station* |
| Measurement of small features (cracks, pitting of steel or concrete) | Direct measurement with scale, laser line or pointer system, stereo visualisation and other photogrammetric techniques   |  |

| | | |
|---|---|---|
| Leak detection and quantification | Physical indicators - dye, particle flow, mechanical flow meter<br>Acoustic techniques - hydrophone, doppler current profilers and velocimeters |  |
| Concrete lining integrity | Sample collection by coring, ground penetrating radar (GPR), seismic techniques |   |
| Water quality parameters | Chemical cells, temperature probes |  |
| Thickness measurement of steel liners | Ultrasonic probe<br><br>*Gauge for metal thickness measurements* | <br>*ROV with ultrasonic probe and scrubber* |
| Mapping of large features | Profiling and navigation sonar<br><br>*Composite image made from several image sonar scans, showing plan view of tunnel* |  <br>*Composite image made from two profile sonar scans, showing cross-section of tunnel with side opening.* |

| | | |
|---|---|---|
| |   *Multiple profile scans assembled to determine volume of material accumulation in tunnel collapse. Also suitable for mapping sediment accumulation.* | |
| Sample collection | Suction carrousel, sampling tray, manipulator |  |
| Correlate all observations into readily accessible report | Use of relational database so that all information is cross-referenced |  |

The last entry in *Table 1* is one of the critical aspects of any inspection. Data must be correlated to a known location so that all information can be tied together. This includes video documentation as well as specific sensor readings at unique locations. Digital video imaging systems make synchronization easier than older analogue systems since each frame carries a time stamp on it which can tie into a comprehensive data base made for this type of inspection and reporting work. Multi-sensor integration into proprietary data acquisition systems can provide a virtual replay of all related data, similar to Geographical Information Systems (GIS).

ASI has developed, maintains and continues to expand its fleet of purpose-built vehicles to conduct civil engineering assessments in a wide range of flooded tunnels, underwater infrastructure, and open-water inspections. Some of these are based on commercially available ROVs that ASI has modified for long excursion capabilities. These are summarised in *Table 2*.

**Table 2: ASI Group Inspection Vehicles**

| *Vehicle* | *Vehicle Name* | *Dimensions L x W x H (cm)* | *Umbilical Length (m)* | *Typical Applications* |
|---|---|---|---|---|
|  | *Pipecrawler* | Inline - 100 x 10 x 10<br>Parallel - 40 x 30 x 30 (adjust to pipe diameter) | 600 | Small diameter service lines and where lines are not completely flooded; can be converted to battery operation using fibre tether for special applications |
|  | *Seabotix LBV300XL* | 53 x 24 x 41 | 250, 750, 1,140 | Small diameter municipal and industrial intakes and outfalls |
|  | *SeaEye Falcon* | 105 x 65 x 78 | 1,100 | Municipal and industrial intakes/ outfalls – ideal for easy bolt on accessories including cameras, sonars, tracking systems, and five function manipulator. |
|  | *Pipeliner 5000* | 140 x 48 diameter | 1,525 | Small diameter municipal and industrial intakes/ outfalls |
|  | *ASI Mantaro* | 220 x 150 x 94 | 10,000 | Long tunnel and pipe inspection, min. 2.50 m diameter. The basic suite of sensors provides detailed visual observations, make large dimensional measurements of tunnel cross-sections and debris piles. Small representative samples can also be collected using the manipulator arm. |

## REMOTE INSPECTION METHODS AND EQUIPMENT

### *Dual Axis Sonar*

Advances in scanning sonar technology and its application are enabling several types of inspection surveys to be conducted under operational flows, providing great cost savings to owners. ASI has designed and built a dual axis sonar system that is capable of operating in high flow conditions and provides accurate dimensional information regarding the structure and accumulated debris.

The sonar is used to collect several thousand point measurements that are then merged into a "point cloud" representative of the structure being inspected. A significant advantage of this type of inspection is that each point has true X, Y, Z values, making accurate measurements possible. The data files can be provided in ASCII text for importing to virtually any CAD program or point cloud analysis and manipulation software.

This equipment was used to accurately map 500 feet of a submerged vertical shaft in preparation for re-lining (*Figure 3*). The surface portion of the structure was surveyed using conventional laser scanning equipment and the two data sets were merged to provide an overall rendering of the surge shaft and tank. This as-built survey provided information that had never been recorded or was lost to the present engineering staff at the facility and was crucial to the success of the shaft repair. Figure 4 identifies the image of a sunken vessel that was surveyed using dual axis sonar fixed to a ROV.

Presentation of the sonar data is one of the keys to the success of this technology. Using animated versions aids in viewing the 3-dimensional aspect of the data but where 2-dimensional versions are required for print, rendering the data into a wire frame or digital terrain model (DTM) is often acceptable.

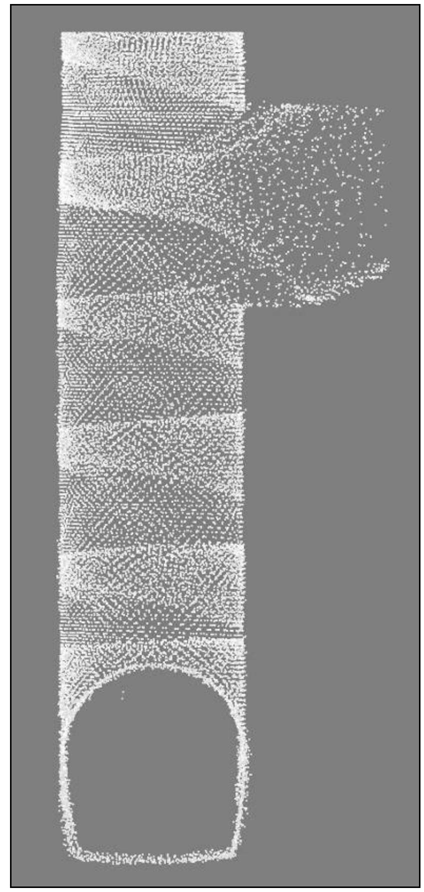


**Figure 3: Point cloud of surge shaft.**

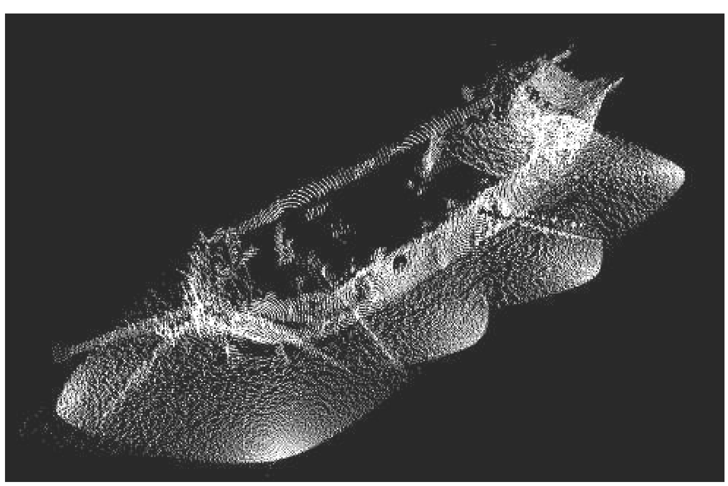


**Figure 4: Image of ship hull created using Dual Axis Sonar**

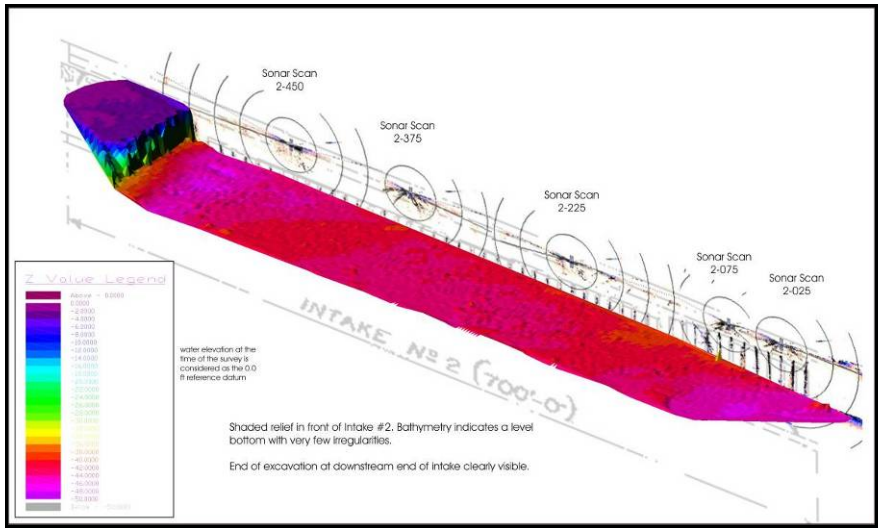



**Figure 5 - Combined sonar image scans with structural drawings and rendered bathymetric data produced this 3-D consolidated survey map.**

The above figure is an integration of three sets of data. Image scans were taken of the intake face to provide a photographic representation of the present condition of the structure. These image scans were laid over scanned images of the structural drawings to clearly indicate areas where debris had accumulated as well as confirm the interpretation of the image scans (presence of submerged components that corresponded with known structures). The dual axis sonar data that was taken in front of the structure was rendered to produce a DTM, representing the bathymetric data in front of the structure.

The example in Figure 6 shows a sonar image scan of two pipe openings in a headwall structure that has been combined with a regular photograph of the above water structure, a sonar image scan of the outlet and the rendered bathymetric data that was collected using a dual-axis sonar system.

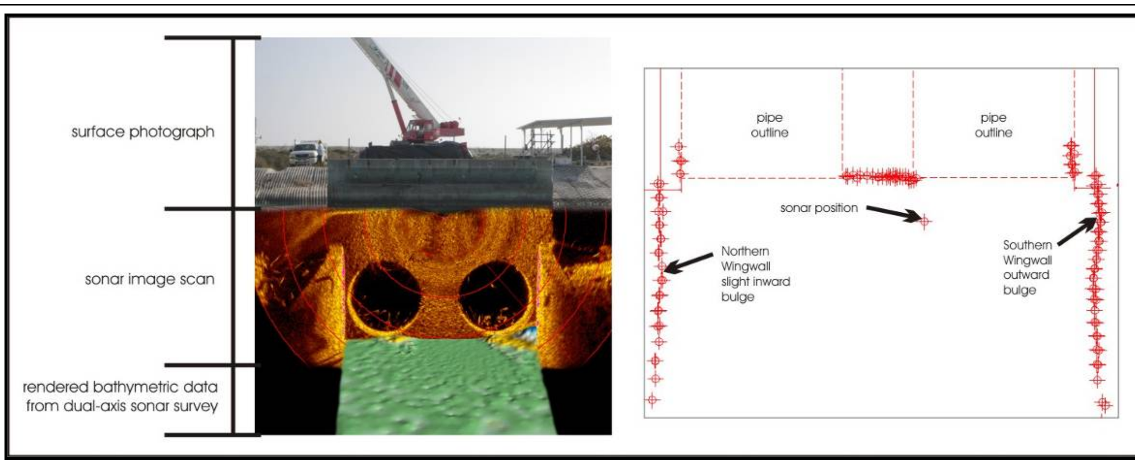



**Figure 6 - Composite image of headwall and slice of point cloud data at springline elevation showing anomaly in wall that otherwise would not have been known.**

Since each point in the point cloud data set represents true 3-dimensional points, a horizontal slice taken through the data at the pipe springline clearly indicates two slight construction anomalies (deformations in the wing walls) that would not otherwise have been known. These types of cross-sections and other data manipulation can be done during the post-processing stages after all inspection assets have been demobilized.

## MARINE GEOPHYSICAL INSPECTIONS - BATHYMETRY

Actively dredging sediment accumulation in reservoirs, forebays, intakes and sediment traps is a costly procedure that must be closely managed to determine when it should be done, and where the target areas are located. During the sediment removal, dredge monitoring by some means of bathymetric survey is the control most commonly used for progress payments to the contractor.

Echo-sounding is the industry standard technique for the collection of water depth data for developing underwater seabed/riverbed/lakebed topography. There are two main types of echo-sounding techniques; single beam and multi-beam bathymetry. Single beam bathymetry (*Figure 7*) is more economical but requires many more passes of the survey vessel than required with multi-beam. Single beam bathymetry employs a single transducer mounted "over-the-side" of the survey vessel.

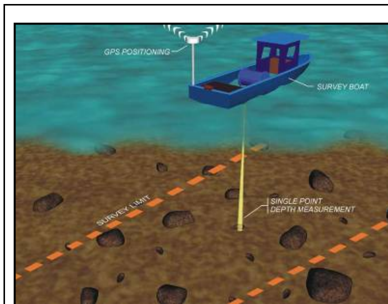



**Figure 7 - Single beam echo-sounder operation**

Bathymetric data is collected continuously along the track line and only directly under the vessel (i.e., not out to either or both sides of the vessel). The spacing of the echo sounding data is directly related to the survey line spacing. One hundred percent bottom coverage is generally not achieved using this method.

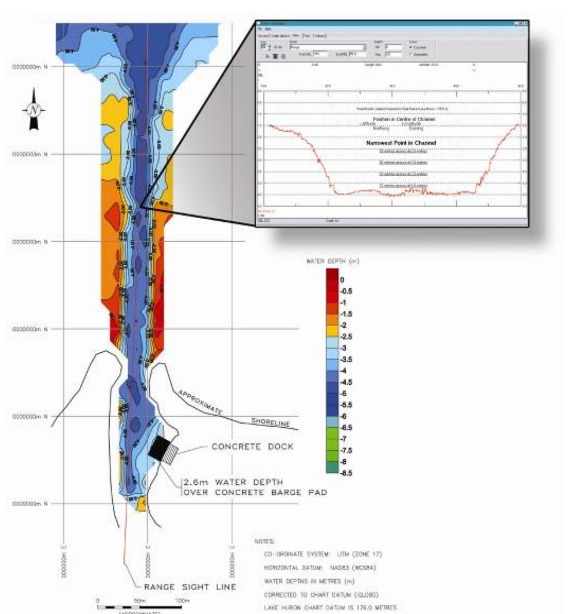



**Figure 8 – Plan view of survey area combined with cross section at a specific chainage. Any location within the survey area can be "sliced" to show existing conditions.**

Multi-beam bathymetry allows large swaths to be surveyed with a single pass of the survey vessel. Since there are multiple beams pointed downward in a swath across the survey vessel's track, bathymetric data is collected along the line as well as out to each side. This type of application is well suited to collecting data over large areas where complete bottom coverage is critical such as revettement pipeline surveys, identification of placement of underwater pipeline, cable, and/or transmission crossings, large bodies of water, etc. The access of the multi-beam transducers' mounting can be rotated to survey vertical faces of dams, pier abutments, and wharves in a single swath.

***Side Scan Sonar***

Side scan sonar is the technique of choice for seabed/riverbed/lakebed imaging. Side scan provides excellent target detection, bottom type classification capabilities, and local geologic interpretation.

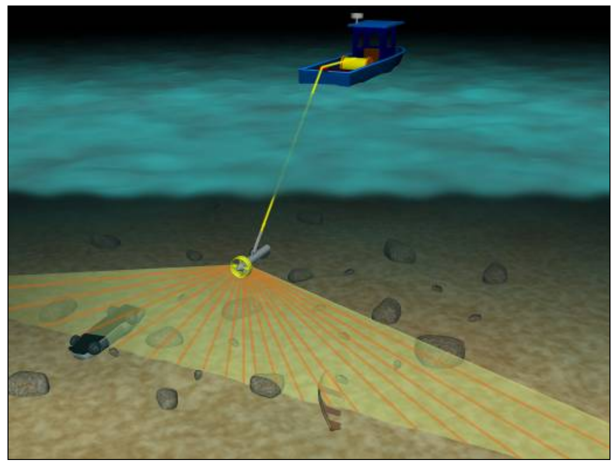


**Figure 9 - Side scan sonar combined with multi-beam sonar can provide 100% bottom coverage**

The side scan is a towed system, which transmits an acoustic beam 90 degrees from the survey vessel's track, and out to each side. This beam propagates into the water and across the seabed/riverbed/lakebed. The bottom roughness and objects lying upon it reflect some of the incident sound energy back in the direction of the sonar. The sonar receives these reflections, amplifies them, and sends them to a sonar data processor and display.

A constant towfish height is maintained with respect to the bottom with the swath width generally being water depth dependent. Typically, the higher the frequency of side scan sonar that is used, the higher the resolution. However, as resolution increases, optimum range decreases and vice versa.

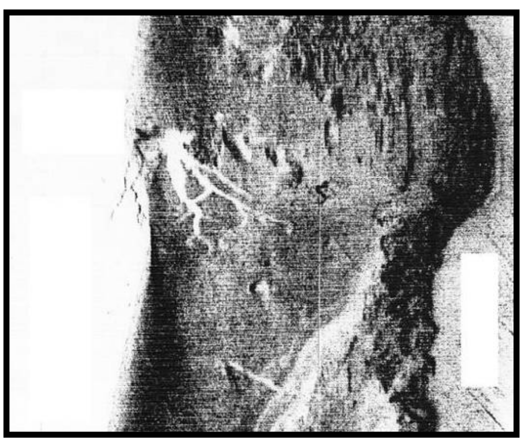


**Figure 10: Side scan sonar imagery of tree on river bottom.**

Images produced by quality sonar systems are highly accurate and can be used to delineate very small targets and bottom features (e.g., holes or depressions in bottom, slumping or bottom failure features, fractures in concrete sills, accumulations of debris, etc.). In the case of intakes and outfalls, side scan sonar is also the best tool to use for the location of assets whose location is unknown. They have also been used to monitor effluent discharge from diffuser nozzles since the discharge typically possesses different acoustical properties than the surrounding water, thereby providing a slightly different acoustic signature. These differences can be due to air entrainment, temperature variance or suspended particulate matter, all which would enhance reflection of the acoustic pulse from the sonar.

Annual inspections can be scheduled independent of plant outages since most of these techniques can be conducted in operational flows. This provides plant maintenance personnel with factual data on which to plan necessary outages and the work tasks.

## VISUAL EXAMINATION

Visual inspection is arguably the most often used NDE technique. Direct visual inspections can be performed by divers and remote visual inspection performed via video camera. The accuracy of underwater visual inspection depends largely on water clarity, lighting, and the skill of the examiner. If the inspection is done remotely, then the ability of the camera to resolve indications comes into play.

Camera systems have evolved rapidly, with those deployed in the underwater market lagging those of the general consumer market. However, adaptation of HDTV cameras, digital video and digital stills cameras are now supplied by several specialist manufacturers for commercial underwater applications.

While many operators still rely on video grabs to digitize the video image, one of the more significant advances in underwater video inspection is the digital camera. A digital stills video camera provides a standard video feed to the surface personnel. When an area of interest is noted, the video image is used to frame the target and a digital still image is taken that has a much higher resolution. A thumbnail version of the image is provided to the operator as an immediate indication of the image quality and content. If the operator decides, adjustments to the camera parameters (focus, iris, white balance, lighting, etc) can be made and additional images taken. Once satisfied with the picture, the final image is normally stored on board the camera in digital format and downloaded after retrieval. Film cameras cannot provide the confidence that a good image has been taken and “video grabs” are highly dependant on a good video image and can never produce the same resolution as a native digital image. The maximum resolution of NTSC analog cameras, after the video signal has been digitized in a DVR or a video server, is 400,000 pixels (704x576 = 405,504), or just above 0.4 megapixel.[1]

Another type of camera that has been deployed in customized housings is the megapixel camera, more commonly used in the machine vision inspection industries and security applications. These cameras can capture and transmit high resolution digital images typically from 3 to 10 megapixel. ASI has conducted research with several cameras in the 6 to 10 megapixel range that were adapted for underwater use in an inspection system requiring very high levels of detail.

[1] http://www.axis.com/products/video/about_networkvideo/resolution.htm

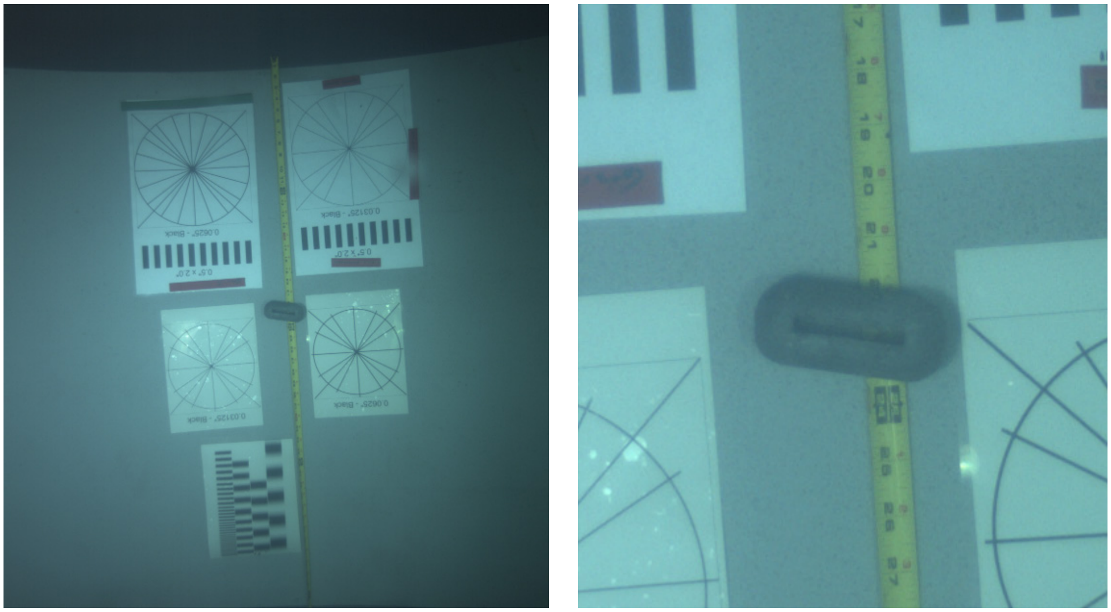


**Figure 11: Underwater image taken with 11 megapixel camera using wide angle lens at 4 feet from target. Image on left cropped to half the field of view, image on right is digital zoom to centre of image, showing clear detail of tape markings.**

### *Close-Range Laser Image Scaling*

Obtaining accurate underwater measurements either by ROV or diver has always been challenging. Conventional measuring devices are, at best, difficult to use underwater. Under most conditions, they prove impractical or impossible to use. Close-range laser image scaling systems like the LazrLyne by C-Map Systems provide precise image scaling from a real-time video image. In the case of the LazrLyne software and hardware package, accurate measurements are possible with the video micrometer feature provided in the software.

The LazrLyne system projects a bright red vertical stripe across the video camera field of view utilizing a miniature solid-state laser diode as shown in Figure 12. The diode is powered by a low voltage DC power supply or battery. It can be mounted on most video cameras and lends itself to either ROV or diver deployment.

The laser stripe is oriented at an angle to the vertical axis of the video camera. The angular orientation of the projection creates an apparent motion of the stripe relative to camera range. To measure an object, the operator pauses the video image and clicks on the laser stripe with the cursor. The software calculates the range and scales the image. It is possible to measure areas, distances, and angles anywhere on the monitor screen. Measurements can also be taken in three dimensions using an "offset" function in the software to compute the height or depth of three dimensional features intersected by the laser stripe.

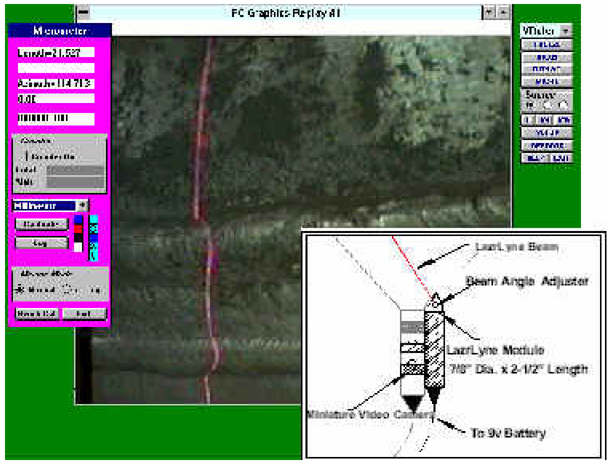



**Figure 12 - Laser Image Scaling projects a bright red vertical stripe across the video camera field of view utilizing a miniature solid-state laser diode**

The laser projection optics can be adjusted by changing the beam angle and focus. This permits use with a wide range of camera optics and working distances. A bench calibration for each specific camera and lens is required to insure maximum accuracy. It is possible to store multiple calibration setups in the system for different situations.

Video field of view, range from the camera to the surface, and the acuteness of the laser stripe angle determine measurement sensitivity. The greatest accuracy is achieved when at close range with a sharp laser angle. Measurement precision of plus or minus two to three thousands of an inch is possible. Accuracy decreases rapidly as range increases. The working distance limit for reasonable accuracy is approximately 24". This is not a serious limitation since most underwater inspection takes place at close range.

## ADVANCES IN NDE TECHNIQUES FOR UNDERWATER APPLICATIONS

### *Ultrasonic thickness measurements*

Underwater inspection of steel structures often requires the accurate determination of remaining wall thickness. Typically, ultrasonic thickness (UT) measurements are taken but obtaining accurate readings under the conditions typically encountered underwater is very difficult and time consuming. Extensive surface preparation is often required and the skill of the operator is a factor as well. Since each reading represents a small finite point on the structure, a large number of readings are required to gain a general indication of loss of wall thickness.

As with surface applied techniques, the need for a more rapid means of collecting data over a large area has led to the use of multichannel UT arrays. Such a system is currently being deployed for ship hull inspections in Brazil by using a crawler style of ROV for areas above and below the water line. With the use of an accurate positioning system, a large area can be covered very quickly.[2]

[2] Triex Sistemas, Rio de Janeiro, Brazil

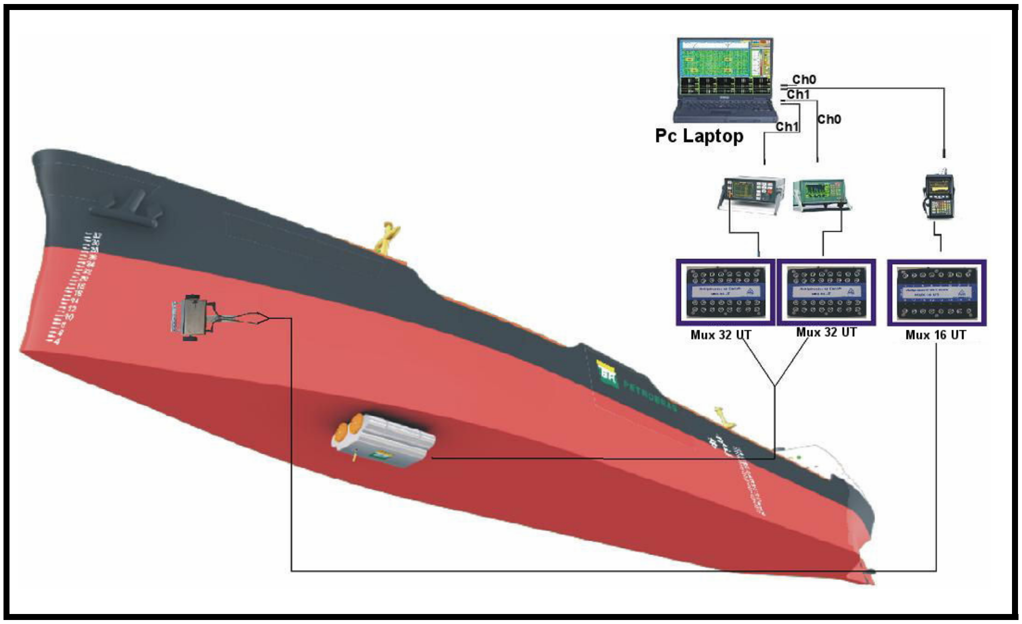



**Figure 13: Deployment of UT multiplex unit for inspection of ship hull.**

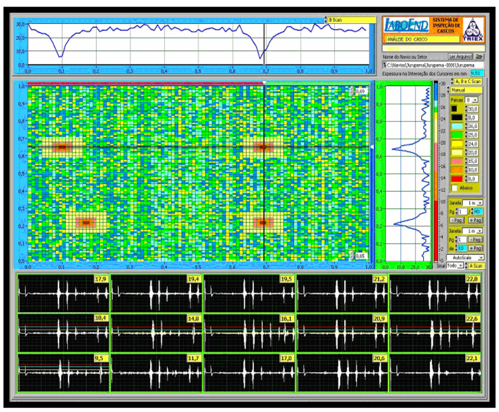


**Figure 14: Presentation of UT readings.**

The figure on the left is an example of UT data presentation developed from the single point A-scan data. Software is used to construct B-scan and C-scan presentations, making the presentation more relevant to the area of the survey.

## *Pulsed Eddy Current*

The Pulsed Eddy Current (PEC) technique has been available for decades but was not adapted to underwater inspection until recently. There are number of advantages over conventional UT. The need for extensive surface preparation is essentially eliminated. The PEC probe does not have to be in contact with the metal surface and can measure through up to 250 mm of marine growth and coatings. Coupling a UT probe with the metal required a clean surface but PEC can measure through corrosion layers as thick as 20 mm and is not affected by surface roughness. Finally, the skill required by the operator is minimized by the fact that the PEC probe does not need to be positioned perpendicular to the surface; accurate reading can be obtained with misalignments up to 30°.[3]

The data collection capability of PEC offers additional advantages but also some limitations. PEC

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[3] OGNL A'dam; A.G. Roosenbrand, P.C.N. Crouzen, J. van der Steen (OGEI/3) Materials & Inspection Engineering Group: Use of Pulsed Eddy Current technology for offshore and underwater inspections - the key to structural integrity assurance; November 2001

averages the metal thickness over the ‘footprint’ of the measurement while UT determines an accurate plate thickness in a pinpoint area. For the purposes of underwater inspection, this offers more of an advantage than a disadvantage. It is possible to determine the section loss trend in a much shorter time, and since underwater durations are often limited by environmental conditions, this can be decidedly advantageous.

The footprint of the eddy current reading is roughly circular with a diameter of about 25 mm when the probe is in contact with the surface. As the probe is moved away, the diameter is approximately equal to the stand-off distance between probe and surface of the steel being measured. As readings are taken, the plate thickness is seen as an average thickness of the area encompassed by the footprint. This makes PEC well suited for determining metal thinning over a relatively large area but limited in its ability to detect very small localized pitting.

Accuracy of measurements is considered to be 5 to 10% of the nominal wall thickness and repeatability at a given point is typically 0.2%. This reproducibility makes PEC an excellent tool for monitoring trend over time.

PEC is easily deployable by diver and special jigs have been developed for deployment by ROVs for the inspection of structures with varying geometries. The jig may be attached to the vehicle or the structure. Figure 15 shows a jig or frame that can be mounted on the ROV. The PEC framework is fixed to the frame of the ROV. The ROV then maneuvers to place the frame against the structure with the PEC probe facing the inspection area. Hydraulic actuators allow movement of up to 1 meter to precisely position the PEC probe for measurements.

**Figure 15: Example of PEC probe positioning frame for use on ROV**

## SUMMARY

The selective utilization of the appropriate tools for underwater inspection can provide owners with inspection results or completion of maintenance tasks that was previously unattainable or could only be accomplished at great cost. Nuclear diving takes advantage of the shielding aspect of containment water to permit controlled, manned entry into these systems to accomplish tasks in a safe, timely and cost efficient manner. Other areas and tasks may be more suited for the deployment of robotic vehicles or remote sensors to gather data or effect repairs. The advancements in robotic technologies, imaging systems and other NDE techniques have gradually extended into the underwater environment. Their application presently supports inspection and maintenance activities for extending the active service life of some of the original nuclear installations.