Submersible ROVs Pioneer Decommissioning of a Legacy Nuclear Fuel Storage Pond – 15368

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ABSTRACT

Submersible Remote Handling Vehicles (ROVs) are being used in innovative ways at the Sellafield decommissioning, reprocessing and nuclear waste management facility in the UK in a legacy fuel storage pond in support of pond decommissioning.

A wide range of sensors and tooling attached to submersible ROVs are being used to characterise the contents of the pond and perform a wide range of maintenance and material retrieval tasks. Visual surveys, sludge and liquor sampling and radiological surveys are just some of the characterisation projects undertaken with the help of the ROVs. The ROVs have also been deployed with tooling including manipulators which can retrieve debris from the pond floor. A variety of mini and work class ROVs are used in the ponds and these can access areas of the pond that the traditional technologies such as long reach tooling and manipulators from overhead cranes cannot reach safely, efficiently and cost effectively. The ROVs are controlled at a distance from the pond to minimise operator exposure to radiation and avoid potential radiological contamination.

Submersible ROVs are widely used in the sub-sea markets, but these are usually unsuitable for immediate deployment in the nuclear industry. Over many years, JFN working in partnership with Sellafield Ltd has selected commercially available ROVs, made any design modifications required and identified and modified or designed and manufactured specialist tooling for these ROVs. These “bespoke nuclear” ROVs must demonstrate that they meet the high health and safety and operational standards and regulations of the nuclear industry as well as the particular operational requirements of the project. Also any modified or new equipment must be compliant with the relevant general EU equipment and machinery standards and regulations. Tooling is developed and trialled with the aid of water test facilities, which significantly increase the probability of a successful outcome on first deployment of the system in the pond.

The use of ROVs in nuclear ponds has proven to be a safer, more efficient and cost-effective solution than available alternative technologies and they are making a significant impact on one of the most complex challenges of Sellafield Ltd’s decommissioning programme.

This paper describes the process involved in developing submersible ROVs and the tooling and services required for the nuclear industry and gives examples of successful tasks being undertaken in a legacy fuel storage pond at Sellafield Ltd.

INTRODUCTION TO THE FIRST GENERATION MAGNOX STORAGE POND (FGMSP)

Refs 1,2,3,4

The First Generation Magnox Storage Pond (FGMSP) at Sellafield Ltd is one of the site's four Legacy Pond and Silo facilities. The pond was constructed in the 1950s and 1960s as an open-air pond to receive and store irradiated fuel from Magnox reactors, and to remove the fuel cladding prior to the fuel being processed.

The pond, which became operational in 1958, was used for 26 years to store and prepare natural uranium Magnox fuel for reprocessing. In its lifetime the facility stored and prepared approximately 27,000 tonnes of fuel, which equates to nearly 2.5 million fuel rods.

The facility comprises an inlet building for receiving fuel, an open-air concrete storage pond, a building containing wet bays for fuel cladding removal (decanning) and a sludge settling pond. The fuel pond is connected to a row of seven wet bays, a special-purpose bay and the magazine transfer bay. The facility was extended through the 1960s to expand pond storage capability and additional large caves (dry shielded cells) were built to improve fuel cladding removal.

It sits in a highly congested area of the site and is surrounded by buildings which originated in the earliest days of nuclear operations on the site, limiting the opportunity for new infrastructure, heavy lifting and temporary facilities.

The fuel was transported to the plant in shielded transport containers, called flasks, with the fuel in open top containers, called skips. These were received by the "inlet building" which enabled transfer of the skips into the pond. An overhead travelling crane supported on a gantry on either side of the 19 metre pond and running its full length, was used to position the skips of fuel in the pond. This "Skip Handling Machine" (SHM) has a mast which extends below the water with bespoke tooling to lock onto the skips. After a cooling period the SHM was used to transfer the skips into the "wet bays" which were extensions of the ponds. They were partly covered by an operating floor with a main penetration to allow operators to carry out fuel operations using long tools to manoeuvre the fuel from skips and into a machine for decanning. The wet bays were used for these operations in the 1960's but then two shielded cells were added to the building to allow decanning to be carried out above pond level with operators using remotely operated tools from outside the cells .

Over the years the pond has accumulated significant quantities of waste materials, sludges from the corrosion of fuel cladding and the fuel itself, fuel fragments, other debris and organic matter which has blown into the pond The skips had been stacked up to three high in the pond and some of these have been dislodged or toppled over and contributed to the accumulation of sludge and fuel debris on the pond floor. The pond contains 1200 skips, an estimated up to 1500 cubic metres of radioactive sludge and 14,000 cubic metres of contaminated water.

The key stages of the decommissioning strategy include a comprehensive characterisation of the pond and its contents, preparation of the pond contents for retrievals and finally the retrieval operations for the fuel, sludge, skips, pond water and any other items. Each of the waste types needs to safely removed and processed through separate routes. A detailed knowledge of the status and location of the contents of the ponds was required, in order to design safe and efficient processing routes.

Due to the high dose rates and corrosive environment in the pond all characterisation and decommissioning work needs to be undertaken using remote handling techniques. These techniques traditionally include bespoke long reach tooling and remote handling systems, deployed from outside of the pond.

THE USE OF ROVS IN THE NUCLEAR INDUSTRY

The submersible ROV market is a large, mature and high technology market mainly serving the offshore energy markets. ROVs are also used in other sectors including science ocean studies; defence; security; film and documentary, etc., but their use in the nuclear industry is relatively small and mainly for visual surveys

Sellafield Ltd has pioneered the use and development of ROVs to support a wider range of characterisation and remote handling tasks, particularly for operations in the FGMSP. ROVs were first deployed in the FGMSP as a tool for visual inspection in 1999. This programme demonstrated that ROVs were capable of operating in the challenging environment and could gather useful information, but it was insufficient as a basis for a robust decommissioning strategy. In 2008, the decision was taken to focus resources on the development of ROVs for the characterisation of the FGMSP. James Fisher Nuclear Ltd (JFN), who had been operating ROVs since 1999 was appointed to develop the ROV capability and extend the scope of operations beyond visual surveys

The commercially available ROVs are unsuitable for immediate deployment in nuclear ponds. Many systems are too large to be usefully deployed in the seven meter deep FGMSP pond, which is filled with skips, sludge and other debris. Other systems cannot withstand the high alkaline conditions of the pond or their electronics the high background radiation levels. Also, the sensors and tooling developed for the traditional off-shore markets often do not meet the requirements and standards of the nuclear industry. Therefore Sellafield Ltd and JFN identified potentially suitable “off-the-shelf” ROVs which could be modified and developed for use in nuclear ponds. This strategy has proved to be a cost effective and successful one and a high risk and costly development of bespoke remote handling systems have been avoided. Close working relationships have been established between Sellafield Ltd, the ROV suppliers, and others in the supply chain including specialist sensors and tooling suppliers, subject matter experts and universities as a source of equipment and expertise. These have been major factors in the success of the ROV projects.

DEVELOPING ROVS FOR NUCLEAR POND OPERATIONS

The introduction of commercially available ROVs used in sub-sea application into the nuclear industry involves several phases. After a potential ROV has been selected, an in-depth analysis of its hardware and software is undertaken to determine its suitability for deployment in a nuclear pond environment. Usually this identifies that some design modifications and further system testing are required. Typically these might include the following:

- Coating key components in a specialised protective layer (Cerakote) to withstand the high PH conditions within the FGMSP and other nuclear ponds. Any aluminium parts are particularly vulnerable.
- Proving that the electronics and fibre optics will operate in a high radiation environment. The electronics and fibre optic of an ROV is exposed to a Cs137 radiation source in a JFN calibration facility and the effect of the radiation on its performance tested and evaluated.

A new suite of sensors and tooling will need to be developed to undertake the specific tasks required for nuclear pond characterisation and decommissioning tasks. The sensors and tooling deployed on ROVs are a mixture of commercially available off-the-shelf, modified off-the-shelf, or a new design and manufacture. Most fall into the latter two categories and require design and manufacture of a skid to integrate and attach the sensor or tool onto the ROV and any required software modifications. The design of ROVs and their accessories is usually modular, allowing capabilities to be added and changed readily on the ROV with a hardware change or a simple software update.

Any new ROV or equipment needs to "approved" for deployment in a safe and structured manner and meet any required regulations or assessments including CE marking, PUWER assessments and HAZOP studies

The availability of off-site water test facilities, such as tanks and docks, plays a key role in the development of ROVs for nuclear use. In these facilities design innovations can be tested, new tooling can be developed through a process of testing and re-engineering and novel techniques and processes can be trialled, especially using ROV with other equipment. In addition the use of these facilities can support PUWER assessments and HAZOP studies of new equipment, procedures and processes. The performance and functionalities of the ROVs and any equipment can be readily demonstrated to all stakeholders in these test facilities, giving them confidence in the performance and reliability of the ROVs in the pond. They are also used by Sellafield Ltd and JFN operators for training and experience on specific tasks which they can then confidently and expertly execute in the ponds. Such intensive testing and training would not be possible in the ponds themselves, because of the uptake of radiation dose and exposure to conventional health and safety risks to personnel.

The key to a successful ROV development is the selection of the best technical and cost effective solution which meet the clients' requirements and budgets and with the client and all stakeholders working closely together throughout the project. Successful innovation is achieved by the highly skilled creative multi-disciplined teams, with many years' experience in ROVs, who are based in both client and supply chain organisations. The teams have the ability to reapply innovations in designs and respond rapidly to new requirements and so provide optimum designs and solutions. They are also experienced in meeting nuclear regulator compliances for new designs which reduces the risk to innovation. This has been facilitated by co-locating JFN personnel, workshops and a testing facility, and holding regular meetings, workshops and brain storming sessions with the client and supply chain.

APPLICATIONS OF ROVS IN NUCLEAR PONDS

ROVs have been used to support a range of operations in nuclear ponds by delivering sensors and tooling to the pond area of interest. They have supported visual surveys, radiation surveys, fuel retrieval and consolidation in storage skips, sludge and liquor sampling amongst many others. ROVs have also been successfully trialled to support the operations of other equipment in the ponds. For example ROVs have manoeuvred equipment into position, attached hoses to equipment and attached slings and hooks from cranes to skips so they can be moved within the pond.

Visual Surveys

Two ROVs were used to access, video and map the contents of the FGMSP with its 1200 skips. The larger work-class Seaker ROV successfully mapped large areas of the pond; however its size restricted it from accessing many of the lower stacked skips. To access these, a mini ROV, the VideoRay Pro4 was used, with a fail-safe manipulator, variable light brightness control and both horizontal and vertical cameras. JFN designed and manufactured a tool with a boom camera to allow the Pro4 to see inside the skips. The surveys provided valuable data about not only the skips contents, but also their position and condition. The Pro4 also undertakes annual visual inspections in the FGMSP to meet a regulator requirement.

VideoRay Pro4 with boom camera in use in test tank Pro4 with gripper

Pick, Sort and Segregate

The visual surveys identified and located a number of loose fuel elements on the pond floor. A bespoke skid was designed for the Seaker ROV with a hydraulically-driven manipulator arm and power pack and after intensive trials and training, was deployed in the FGMSP to pick up the loose fuel elements and place in a skip. The fuel within the skips also needed to be sorted and the ROV with its manipulator arm was successfully able to sort, segregate and consolidate fuel between containers as well as from the floor to containers. By early 2013, more than 4,500kg of fuel rods using ROV technology have been sorted and segregated, and some 50kg of spent fuel has been recovered from the pond floor and placed into containers ready for export. This work is on-going.

Sludge Retrieval

Originally, it was planned to design and manufacture complex bespoke equipment to remove the sludge from the ponds, but now solutions utilising ROVs have been developed and trialled. Significant savings can be made for this task using ROVs rather than bespoke equipment.

In a successful trial in the FGMSP, an eductor was attached to the ROV and lifted sludge from the bottom of the pond. The eductor device is a powerful jet pump that creates a negative pressure differential that draws the sludge up through a thick hose. Radioactive sludge to a depth of 30 centimetres was successfully removed from a small area of the pond floor right down to the concrete base slab. This capability could be used to help pond floor clearance and will provide access to the containers of nuclear fuel that needs to be retrieved and moved to modern storage. The radioactive sludge is thick and although the eductor had been previously trialled using simulant materials, there was no guarantee that it would be effective when introduced into the FGMSP. Video footage was taken by the ROV and it shows this grey sludge being pulled up through the hose and the yellow uranium is clearly visible. Further trials are now being carried out to capture and temporarily store the sludge, before it is turned into a consistency suitable to start pumping it across to the new Sludge Packaging Plant (SSP1) for plant commissioning. [Ref 5]

Another sludge retrieval trial was undertaken using a sea dock as the test facility. This trial trial involved the deployment of the equipment and relevant mock-up kit required onto the bed of the dock using a barge crane. This equipment included a tethered slurry pump, ROVs, a skip and dumpy bags filled with sludge simulant. One ROV was used to manoeuvre the slurry pump into position on the bed of the bay and another ROV was used to attach the discharge hose from the pump to the skip and also supported the deployment of the inlet hose used to perform the sludge pumping operations. The sludge was discharged into a filter bag lining the skip; when lifted out of the dock, the water drained out, leaving only the sludge. The trials successfully demonstrated that sludge could be retrieved and transferred using this technique and that filter bags could be used to de-water sludge. The trial was commissioned by Sellafield Ltd’s Pile Fuel Storage Pond, who need to transfer sludge within the Pond Decanner Bays and discharge it into the main pond

Moving Skips

The skips in the FGMSP are usually moved by the “skip handling machine” (SHM) which has a mast which extends below the water with bespoke tooling to lock onto the skips. However some of the skips have toppled over or become misaligned and are therefore no longer accessible to the SHM. These skips need to be repositioned and re-aligned to allow retrieval and relocation by the SHM. The JFN and Sellafield Ltd ROV project teams developed the concept that the ROVs could be used to attach or position “tools” onto the skips from the SHM in crane mode to support various decommissioning tasks. This approach is ideal for the repositioning and re-alignment of skips and working in partnership with Sellafield Ltd, the equipment and methodology was developed and trials undertaken in the Sellafield Ltd inactive test pond. A bespoke lifting frame with four chains (or legs) was developed and deployed from the facility crane representing the SHM and this was lowered into the pond to allow a Seabotix ROV to attach the chains onto the lifting features of the skip in the pond. The remotely controlled ROV with lights and cameras was driven to the exact location on the skip and the ROV manipulator attached slings and hooks between the skip and lifting frame. Once the lifting frame was firmly attached, the crane manoeuvred the skip into the desired position. The trials were successful and the JFN and the FGMSP project teams are continuing to work together on demonstrating and practising the technique. The use of ROVs to connect the SHM to the skips potentially replaces the more costly alternative of specialist tooling developed for the SHM to enable attachment to and subsequent lifting of the skips.

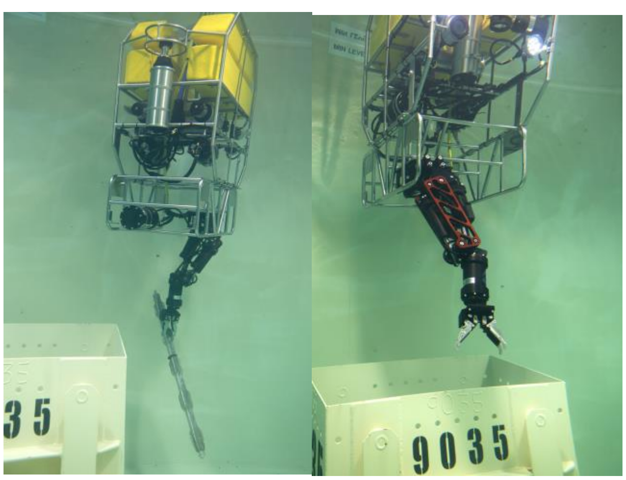
Other Applications and Proven Capabilities

These include radiation monitoring, temperature measurement, oxygen measurements, sludge sampling, pond water sampling, and size reduction task. Several applications are in development.

ROV TOOLING DEVELOPMENTS

Fail Safe Manipulators

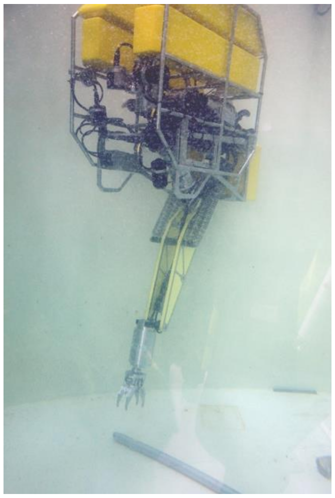
A fail safe manipulator i.e. designed to release its contents under fault conditions and loss of power, is an essential requirement for work in the ponds, to avoid the scenario of the ROV being unable to release ILW material from its gripper. For example, a fail-safe manipulator was developed for the VideoRay with a Closing Force: 3Kg and able to lift a 40Kg using tether. Barbs on the gripper increase gripping effectiveness.



Hydraulic Manipulator deployed on the Seaker ROV

Electric Manipulators

Hydraulic manipulators were the first type to be used in ponds, but electric ones have been developed in response to a Sellafield Ltd requirement to reduce the risk of contaminating the ponds with hydraulic fluids. Not only is this risk removed but the electric manipulator lifetime maintenance and operational costs are lower than their hydraulic equivalents. JFN worked closely with a specialist company and market leader in underwater robotic electric manipulator arms. Their standard manipulators products were re-engineered for use in nuclear ponds, which included fabrication from stainless steel rather than aluminium to withstand the high PH of conditions the FGMSP. A new gripper was designed for general manipulator type tasks and this also has a fail-safe mechanism. Two electric manipulators were developed: e a “forward facing manipulator” and an “underslung manipulator”. These were extensively trialled and demonstrated to the client at all stages of the development in a JFN test facility.



CMS electric underslung manipulator with jaws open, deployed on the Seaker ROV.

Gamma Dose Meter

JFN developed a gamma dose meter for deployment with ROVs for dose rate surveys in nuclear ponds and other potential radioactive environments. The probe is small enough to be mounted on a mini ROV without affecting the ROV buoyancy. No additional cabling is required with power and communications via the existing ROV umbilical cable and there is no degradation of submersible performance. The probe measures dose rates from 100 mSv/hr to 8Sv continuously with the data transferred back to the control station. The dose meter is based on a state-of-the-art, off-the-shelf gamma probe and dose meter, but a product development programme was required to re-engineer and integrate these into the ROV to produce a reliable working system. The JFN Gamma Dose Meter was developed for use with the VideoRay Pro4, but can be adapted for integration with any ROV platform.

Gamma probe attached to the VideoRay Pro4

Gamma dose meter components

BENEFITS OF USING ROVS IN THE NUCLEAR INDUSTRY

The ROV programme offers solutions to characterisation and decommissioning problems not currently available with existing and planned technologies. This innovative use of ROVs in the FGMSP has had a significant positive impact on the FGMSP decommissioning programme. ROVs are also being increasingly deployed in other Sellafield Ltd facilities and it
Is widely recognised that ROVs are now essential as future tooling to manage critical facility risk reduction, due to acceleration of programme delivery.

ROVs provide benefits in the following key areas:

Improved Characterisation

The ROV programme supplies high quality characterisation data faster and in greater quantities than alternative techniques

The ROVs can access all areas of the ponds which other remote handling methodologies cannot; therefore new remote handling technologies would have had to be developed.

This data has been used to underpin the Sellafield Ltd decommissioning strategy and give increasing confidence in the costs, schedule and technical feasibility of downstream decommissioning projects

Cost Savings

The overall cost of the ROV programme is considerably lower than the alternatives.

The ROVs are able to achieve tasks which did not have any available benchmark methodology, removing the cost of developing a technique

Development costs are minimised by using mature COTS technology from the offshore industry

Innovation Helping to Provide Solutions

A mature technology have been taken from other industries and used innovatively in the nuclear sector to provide cost effective, quick and safe solutions. This has been achieved by expert teams from client and supply chain organisation working in partnership.

Programme Acceleration

Work has been completed ahead of programme

The modularisation and versatility of the ROV and the associated equipment reduces the cycle time from project commencement to completion

The team is progressing innovation for tomorrow's projects, today. This process ensures their smooth and timely transfer into operations

The ROVs are efficient and reduce the time taken to carry out the activities, compared with traditional methods. The ROVs can deploy to the place of work very quickly.

The JFN test tanks support development of concept designs and in the final stages of the project final testing and operator training.

Maintenance and Reliability

The ROVs are proven to be very reliable.
The capital cost of the ROVs and spare parts is low compared to the alternative technologies. Several systems have been purchased so that there is no downtime in the event of failure.

Risk Reduction

The programme has been successfully built up out of small increments with minimal novelty at each step

Each new ROV project builds on the knowledge and experience from previous projects. The methodology of develop – test – refine – train and rehearse minimises risks when a new technique is deployed.

The ROVs can be readily and cheaply tested in water test facilities and operators trained so they have the skills to deliver in an efficient and effective way, which reduces dose and risk on plant.

The continuity of personnel has assisted in delivering exemplary health and safety statistics for the ROV projects

ROVs are a tried and tested delivery platform for tooling and the risks associated with introducing bespoke equipment and new technologies are removed.

SUMMARY

Working closely with Sellafield Ltd and ROV suppliers, JFN has adapted commercially available ROVs from the off shore sector and provided innovation in design, tooling and deployment to support characterisation and remote handling tasks, which could not be addressed by conventional technologies. The ROVs programmes have delivered significant milestones in the clean-up of the First Generation Magnox Storage Pond.

ROVs with cameras, sensors and tooling provide the ideal vehicle for undertaking a wide range of characterisation and remote handling tasks within nuclear ponds. Visual surveys, sludge sampling, radiological surveys are just some of the characterisation projects achieved with the help of ROVs. Manipulators have picked up fuel elements and debris from the floor of the pond and fuel elements have been sorted and segregated within the storage skips. Other tooling deployed on ROVs has included shears, cutters, and pumps.

The key to the successful development and deployment of ROVs is the selection of the best technical and cost effective solution which meet the clients’ requirements and budgets and with the client and all stakeholders working closely together throughout the project. Successful innovation is achieved by the highly skilled creative multi-disciplined teams, with many years’ experience working with ROVs in the nuclear sector, which are based in both client and supply chain organisations.

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