

Commissioning and Operation of a Robotic Arm for Waste Retrieval at Trawsfynydd NPP, North Wales - 12091

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ABSTRACT

Trawsfynydd is one of the UK's first generation Magnox nuclear power plants. It started operation in 1965 and ceased generation in 1991.

Before the site can enter the "care and maintenance" phase a number of wet and dry waste stores around the site must be emptied and their contents made safe. Wet wastes include sludges and resins produced during the operating life of the NPP. The sludges and resins are stored in a number of different tanks that vary significantly in terms of size, shape, internal features and access.

A dexterous long reach manipulator arm has been designed and built to facilitate tank clearance. Commissioning of the arm was carried out in parallel with Factory Acceptance Testing (FAT) at the manufacturer's site in Colorado, USA. In addition to basic functional testing this work included a full range of task based testing to ensure that the arm, tools, control system and support equipment were thoroughly exercised in representative conditions.

Trawsfynydd is one of the lead sites in the UK's program for nuclear plant decommissioning. As such the lessons learned, both in terms of technology and process, will be applicable across the remainder of the fleet.

INTRODUCTION

Trawsfynydd is one of the UK's first generation Magnox nuclear power plants. It started operation in 1965 and ceased generation in 1991. Both of its reactors were fully defuelled and all fuel removed from site by 1995. Trawsfynydd, like the other Magnox NPP, is owned by the UK government's Nuclear Decommissioning Authority (NDA) and operated by Magnox Limited, a company owned by Energy Solutions Inc.

The current preferred strategy for decommissioning the Trawsfynydd site, like all UK Magnox nuclear power stations, is deferred site clearance, allowing for total site clearance around 100 years after cessation of generation. This approach minimizes risk to workers, the public and the environment; minimizes waste volumes; is technically straightforward and makes financial sense. Before the site can enter the "care and maintenance" phase a number of wet and dry waste stores around the site must be emptied and their contents made safe. Wet wastes include sludges and resins produced during the operating life of the NPP. The sludges and resins are stored in a number of different tanks that vary significantly in terms of size, shape, internal features and access. The NDA has placed significant incentives on Magnox to recover and process these wastes safely and efficiently.

A number of options were considered for waste retrieval, these included making significant civil modifications to the buildings, use of remotely operated vehicles and deployment of a tele-operated manipulator through existing penetrations into the tanks. An initial evaluation of the tasks required, ranging from bulk sludge removal, separation of solids from sludge, buffer

storage of solids, washdown and retrieval of the inevitable miscellaneous solids, indicated that there would be significant challenges associated with any of the approaches.

Following extensive evaluation, including a range of feasibility studies, it was decided to develop a manipulator based system.

THE MANIPULATOR SYSTEM

The greatest difficulty in accessing the tanks is the buildings within which they are located. The civil structures surrounding, and particularly above, the tanks preclude use of the long reach manipulator arms that have been used for many years across the Magnox fleet. The low headroom (< 2.5 m) above some of the tanks makes the deployment of any work performing system particularly challenging.

Access to all of the tanks is from plant rooms located directly above and, in most cases, is through existing penetrations. The plant rooms are congested with a range of pumps and valves. Entry to these areas is limited and designed for occasional man access and not for new equipment installation. There were significant advantages in being able to access the plant rooms with only minimal modifications to existing doors and walls.

Internal views of two of the four different tanks (figures 1 and 2) give some idea of the difference in their internal structure. The pictures do not give any idea of the range of waste forms that exist below the level of the supernate. The waste includes solids, liquids, resins, sludges and a diverse range of miscellaneous components.



Figure 1: Internal view of resin vault



Figure 2: Internal view of main sludge vault

It was clear that to carry out the task efficiently, whether through use of pumps, vacuums, eductors, water jets, scoops or shovels, it would be necessary to have a dexterous deployment system capable of placing a tool at a range of locations in each of the tanks. Analysis of the key tasks gave rise to the basic functional requirements for the manipulator, a payload of approximately 45kg (100lb), a horizontal reach of approximately 4.5m (15ft) at a depth of approximately 10m (32ft) below the top of 0.25m (10 inch) diameter access.

A contract for the design, manufacture and testing of the “Rotary Deployment Arm” (RDA) was awarded to SA Technology through a consortium, now known as ACTUS, of British nuclear engineering companies. The ingeniously designed, folded telescopic, manipulator that can be deployed into the tank from a rotating frame mounted on a mobile cart was described in a paper given at this conference in 2011 (Reference 1). The RDA incorporates a five section telescopic mast, a two stage hydraulic elbow joint, a telescopic forearm and a two axis wrist carrying a camera and hydraulic gripper. Many of the RDA components are manufactured from carbon fiber which allows the relatively long slender arm to carry a significant payload.

A number of important design decisions were required in order to reach the final solution. In addition to the basic payload and reach requirements outlined above, a review of likely tasks provided an understanding of the operability of the arm. Some of the planned tasks, such as maneuvering a sludge retrieval hose around the tank, require a moderately robust but simple system. Given the mechanical challenges of designing a system compact enough to be deployed from existing plant rooms there were clear temptations to keep instrumentation to an absolute minimum and remove the need for significant electrical cables in the telescopic arm. However whilst there were some very simple tasks that could be tele-operated with visual

feedback from one or two TV cameras there were also some complex tasks requiring fine control and accurate placement. In addition, other activities are to be carried out fully submerged with no visual feedback available.

An early design decision was made to incorporate resolvers for full position feedback and a six axis force / torque sensor for force feedback. Whilst providing a wide range of opportunities for control and feedback the incorporation of this instrumentation in an already mechanically complex system would undoubtedly raise some challenges during commissioning.

Until the clean-up tasks are complete we will not know whether the complexity versus simplicity decisions were correct.

NON-ACTIVE COMMISSIONING

Commissioning of the arm was carried out in parallel with Factory Acceptance Testing (FAT) at the manufacturer's facility in Colorado. In addition to basic functional testing this work included a full range of task based testing to ensure that the arm, tools, control system and support equipment were thoroughly exercised in representative conditions.

Acceptance criteria for basic functional tests are generally straightforward to determine, agree and assess. It is more challenging to agree appropriate acceptance criteria for operability based assessments when carrying out task based activities. It was clear from when test plans were first drawn up that qualitative as well as quantitative measures would be required. The successful completion of these tests owes much to the ongoing dialogue at both project management and technical levels that ensured that the objective of tests on "controllability", "vibration", "smooth low-speed operation" were well understood by all concerned.

Three particular aspects are worthy of further discussion, the use of the force torque sensor, hose management and the design of ad-hoc tools.

Force torque sensor

Recognizing the compliant nature of the slender arm and the range of likely operating modes it was agreed that a force reflecting joystick would not be an appropriate method of operating this manipulator. The purpose of the force torque sensor is to provide some protection to the arm in extreme configurations or payloads and to provide feedback to the operators during certain tank clearance operations.

The first version of the HMI (Human Machine Interface) display provided operators with a graphical view of the wrist with a real-time graphical indication of forces and direction. This display gave the operators a quick and unambiguous indication of the direction of forces / torques and proved useful in diagnosing the cause of an overload or high force warning. However this style of display was of limited use to operators during tasks such as scraping and shoveling that require tools to be kept in contact with the surface of the tank. After trialing a number of options a simple rolling oscilloscope style display showing all three force and all three torque axes plotted against time over a rolling period of about one minute was found to be most effective. It was not immediately obvious that this style of diagnostic display would be effective, however the operators were able to rapidly assimilate the relevant data and take intuitive action much more effectively than when presented with the same data in other formats.

Umbilical management

Management of external hoses or umbilicals in a remotely or tele-operated environment is always challenging. Hose control would normally be carried out using an active or passive system to vary the length of hose deployed within the tank whilst keeping the tension reasonably constant.

The majority of the residual waste in the tanks is to be recovered using a simple tool attached to a heavy duty 75 mm hose. Due to potential contamination of the external surfaces of the hose, its large bend radius and space limitations in the plant room it was decided that the full length of the hose would need to be deployed permanently into the tank with the retrieval tool. Without some form of hose management system this would result in a large and poorly controlled loop of hose within the tank in many of the retrieval configurations.

A number of options for hose management were debated, these included entirely passive options using floatation collars, active systems that would attempt to control the hose based on RDA configuration and constant force tensioner systems. The compact size of constant force springs and a wire rope pulley permitted design of system that would fit readily into the available space in the plant room. There were a virtually infinite range of options on how often and at what spacing to attach the wire rope to the hose.

Initial trials were carried out with the wire attached to the bulk retrieval tool and passing through four fixed rings at locations equally spaced along bottom half of the hose. The results, although at times encouraging, showed a significant lack of repeatability due to the relatively high friction between wire and locating rings. On some occasions hose behavior was straightforward and manageable. At other times, with the RDA in the same configuration, the hose would loop and become twisted. The attachment devices to the hose were modified to incorporate a swivel, this resulted in much more repeatable behavior. Unfortunately this just meant that in certain configurations it could be guaranteed that the hose would become unmanageable.

The force / torque sensor provided valuable information on the loads and rate of change of load on the manipulator as a result of attempting to change configuration of the bulk retrieval tool and hose. At times all operators were surprised by the high levels of force that could be exerted by the hose when in apparently benign orientations.

Further testing indicated that better performance could be achieved by varying the spacing of the attachments, relatively close together near the tool, further apart away from the tool, with the uppermost attachment point about mid-way along the hose. Supplemented by adjustments to the wire tension this arrangement gave much improved results. However certain configurations could still result in hose kinking or high loads on the RDA. A final modification, involving moving the main anchor point to about 600 mm behind the solid section of the tool, was carried out. Placing the anchor point on the hose rather than the tool changed the behavior of the hose significantly, it became immune from kinking and the loads on the RDA wrist not only reduced but varied smoothly and repeatably with varying configurations.

Figure 3 shows the RDA carrying the bulk retrieval tool with the hose management system in operation.



Figure 3: RDA during testing of bulk hose management

Tool design and optimization

A wide range of tools were designed, developed and tested during the course of the project. A number of the tools, for example the petal grab and high pressure water jetting tool are active tools requiring their own services. These services are provided through individual cable reelers installed into the tank with the tools. It is anticipated that a significant number of passive tools, rakes, shovels, scrapers will also be required. A number of these have been manufactured and tested with simulated waste. However it is anticipated that a number of alternative designs will be required once retrievals are underway. For this reason it was decided to design a simple universal attachment system that would allow the RDA to pick up ad-hoc tools at different but well defined orientations. The coupling incorporates a compliant mount as well as a fitting to allow unused tools to be stored securely in a rack mounted within the tank. During operator training a number of simple tools were manufactured and tested. The combination of a compliant mounting block and effective force feedback allowed operators to carry out difficult tasks with simple tools in a remarkably quick and safe manner.

ACTIVE COMMISSIONING

With no test or rehearsal facility available on site at Trawsfynydd it was necessary to complete commissioning of the arm in one of the active facilities. A program of activities to test the arm as thoroughly as possible within the tank but keeping it out of the active liquor was established.

The RDA has been successfully maneuvered into the plant room above one of the resin vaults. Figure 4 shows the RDA in position in the plant room just before deployment in the tank. The compact size of a manipulator arm able to reach 10 meters down, reach out 4.5 meters and carry a payload of 45 kg is apparent from the figure. The RDA has then been successfully deployed into the tank by rotating its support frame on the transport cart. All joints have been exercised to their maximum extent whilst keeping the arm above tank waste level. The bulk

retrieval tool has also been deployed into the tank further testing carried out with the tool coupled to the RDA.



Figure 4: RDA in position in a resin vault plant room

The task of removing legacy waste from the first of four storage areas on site is due to commence soon.

LESSONS LEARNED

During the course of a challenging development project such as this it is inevitable that all parties will have opportunities to reflect on a number of decisions made.

An important decision from Magnox was to ensure that operators were well represented throughout the project lifecycle. This included attendance at concept reviews and design reviews where, for example, the prototype HMI was first presented. Magnox then committed to send the operators for extensive training during the factory acceptance testing. This proved to be a real benefit as many minor changes, whether to HMI or tooling, could be incorporated at the appropriate stage in the system development. Installation and commissioning of the RDA in the resin vault has greatly benefited from having station operatives directly trained on the operation of the arm.

The original design intent was to be able to install the RDA in the plant room, with only minor changes to doors and walls. Extensive CAD modeling based on site surveys demonstrated that installation would be feasible without any modifications within the plant room. However, during the services installations work (power and signal cabling) it became evident that removal of additional plant was required to ensure that the arm could be safely installed and maintained.

Magnox, both through and with our main contractor ACTUS, retained a close technical involvement with SA Technology throughout the project. This assisted in creating a very open and honest working environment which was very important when resolving issues that occurred

during the extensive test period. Extensive testing that focused on tasks rather than basic functionality revealed a number of issues that, even with the benefit of hindsight, would not have been revealed during design reviews.

When reviewing the overall project it is apparent that much emphasis was placed on timescales for successful testing and delivery of the RDA to site. A high performance arm has been designed, developed and extensively tested in a very short period of time. The overall project provided a number of other challenges, particularly the development of site based plant for waste processing and storage. Some of these challenges still require resolution before waste retrieval using the RDA can commence.

SUMMARY

Safe and effective clean-up of legacy wastes is a key element in the overall plan to allow Trawsfynydd NPP to enter its “care and maintenance” phase of decommissioning.

It is anticipated that as the project moves from the commissioning phase into full scale waste retrieval that the benefits of the approach described will be fully realized

Trawsfynydd is one of the lead sites in the UK’s program for nuclear plant decommissioning. As such the lessons learned, both in terms of technology and process, will be applicable across the remainder of the fleet.

REFERENCES

1. Marc Rood, Scott Martin, Bradley Walpole S.A. Technology “Use of Tank Retrieval Manipulator Systems in Nuclear Decommissioning”, WM2011 Conference, February 27-March 3, 2011

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