

Successful Use of Remote Engineering Technology to Upgrade Electrical Power Supplies to a Plant Producing Vitrified Highly Active Waste

J.P. Harken,
Nexia Solutions Ltd,
Havelock Road, Workington, Cumbria CA14 3YQ,
United Kingdom

ABSTRACT

This paper describes a remote handling intervention project on the Sellafield site in the UK that successfully replaced a critical part of a critical plant in a highly radioactive and contaminated cell.

The aim of the project was to replace the existing design of electrical power supplies inside the plant that vitrifies high level liquid waste with a new improved design. The project designed and built a hydraulic manipulator and associated workheads and tooling to be deployed in cell to remotely replace the power supplies. As part of this replacement process, the project also designed and built a drilling rig to remotely drill holes through the cell wall suitable for the new design of electrical power supplies.

OBJECTIVE OF PROJECT

The objective of the Waste Vitrification Plant (WVP) Through Wall Crossings (TWC) Project on the Sellafield site in the UK was to remotely replace a critical part of a critical plant in a highly radioactive and contaminated cell.

The aim was to replace the existing Through Wall Crossings on two process lines (Lines 1 and 2) with a new improved design.

WVP takes the liquid High Level Waste streams from the UK nuclear reprocessing industry and vitrifies them to a solid form for safer long term storage. As part of this manufacturing process, inductor stacks heat the melters to the temperatures required for vitrification.

An inductor stack consists of seven heating zones, each of which has the electrical power supplied to it by means of a Through Wall Crossing. Each of the seven TWCs consists of two copper pipes housed within insulating blocks made of an asbestos based cement. The copper pipes run in pairs (one feed and one return) in each Through Wall Crossing straight through the cell wall and into the cell interior to the induction stack. The electric

current flows along the copper pipe wall whilst cooling water flows down the bore of the pipe.

Certain sections of the copper pipes in cell, as they pass through the cell wall and also enter a vertical end post are not contained within the insulating material and are exposed (see Fig. 1.). The middle section of the TWC inside the cell is keyed onto a vertical central support bracket, and the sections of the TWCs that lie within the cell wall consist of individual bricks of insulating material, all clamped together by tie bars passing through them.



Fig. 1. View of the through wall crossings inside cell

SCOPE OF PROJECT

In 2001 WVP had to cease production on both Lines 1 and 2 for a short period of time due to operational problems with the TWCs. A short term solution, involving the cross over of electrical connections inside cell, was quickly implemented to enable WVP to re-start production.

However any further TWC failures could have led to an extended shutdown period. Because of this, although this short term fix enabled the plant to run successfully, it was always regarded as a temporary solution whilst the design and implementation of a more permanent longer-term TWC replacement system was progressed.

Nexia Solutions Ltd were approached in 2001 to design and develop the equipment and methodology to implement this long term solution in 18 months. This evolved into a complete turnkey project involving the feasibility investigation, equipment specification, design, manufacture, assembly, testing, development, operator training, and finally deployment and operation on plant of a remote handling system and associated tooling to replace the TWCs. The work was funded by British Nuclear Group.

This long term solution involved the complete removal of the previous design of Through Wall Crossings (both the in cell and out cell components) and their replacement with a new improved design which is

- compatible with both the previous and new melter control systems
- much easier for the plant operators to routinely effect a water tight seal at the end of the crossings
- much easier to replace in the future if one was to fail
- less susceptible to future problems such as mechanical damage

The main operations performed on plant consisted of the following:

- Removal of the in cell sections of the existing Through Wall Crossings
- Drilling out of the existing holes in the in wall sections of the Through Wall Crossings
- If the drilling had been unsuccessful then removal of the in wall sections of the Through Wall Crossings would have been undertaken (this was referred to as the Pull/Push recovery strategy)
- Deployment of the new Through Wall Crossings

The project itself was broken down into four distinct phases.

- Phase 1 involved feasibility investigation and then development of the optimum methodology, procedures and techniques for carrying out the removal/replacement tasks in an efficient and safe manner.

- Phase 2 involved the specification, design, manufacture and assembly of the equipment for both the in cell and out cell operations on both Lines 1 and 2. This required manufacture of 2 complete sets of equipment for the out cell operations and 3 complete sets of equipment for the in cell operations.
- Phase 3 involved comprehensive functional testing and then development trials of all the equipment followed by extensive operator training of every possible scenario on full scale mock ups. Two full scale mock ups and a third smaller one were built to enable parallel development streams to be simultaneously undertaken for the numerous pieces of equipment that had to be proven and developed in the challenging timescale.
- Phase 4 was to undertake the removal/replacement operations on site for both lines, using the fully trained team with support from plant

HISTORY OF PROJECT

The project began in the summer of 2001 with an optioneering study to investigate the feasibility of replacing the TWCs. This involved taking a 'back to first principles' approach by analysing the problem with lateral thinking and brainstorming sessions.

It is interesting to note that the original Value Engineering (VE) study's preferred option for replacing the TWCs was to push the in wall sections into cell, rather than drilling the holes out, which was thought to be too difficult to repeatedly achieve the level of concentricity required. It was only slightly later in the project, because of concerns over how difficult it may be to push the TWCs without damaging the wallbox, the risk from contamination and radiation shine paths, and after further investigating the feasibility of drilling, that drilling was selected as the preferred method. Thus pushing of the TWCs was relegated to the recovery scenario or fall back position if drilling failed on plant.

In the optioneering study, the task of removing the in cell sections of the Through Wall Crossings was analysed by breaking it down into five main areas for consideration:

- Location of cuts
- TWC Removal Technique
- TWC Cutting Technique
- TWC Clamping Technique
- Equipment Deployment Technique

Each one of the above areas was analysed to generate as many possible solutions as possible. The conclusions of this study included the facts that TWCs should be cut at both ends where the copper pipes are exposed, and that shearing and sawing were the preferred cutting techniques.

As a result of the initial optioneering study, five alternative scheme options were devised and drawn up.

- Option 1: Crane slung cutting tools and simple manipulator
This proposed the use of cutting tools slung from the in cell crane and a simple hydraulic manipulator (not a robot) to clamp and remove the TWCs.
- Option 2: Crane slung cutting tools and crane slung clamp
This again proposed the use of cutting tools slung from the in cell crane, but in addition the clamp to remove the TWCs would also be crane slung.
- Option 3: Crane slung cutting tools and platform mounted clamp
This again proposed the use of crane slung cutting tools, but with the clamp to remove the TWCs mounted on an adjustable platform (fork lift principle).
- Option 4: Platform mounted cutting tools and clamp
With this option both the cutting tools and the clamp were to be mounted on an adjustable platform
- Option 5: Proprietary robot
This proposed the use of a proprietary robot to cut and remove the TWCs

After these 5 options went through a formal comparative analysis process, Options 1 and 2 were accepted for further progression to scheme design. After a while, Option 2 was de-selected due to concerns over the controllability in cell of a clamp slung off the crane when removing the TWCs. Thus Option 1 was the one taken forward for detail design and manufacture.

By June 2002, the assembly and functional testing phase of both the in and out cell equipment was well underway, and the trials on the mock ups had started. August 2002 saw the start of the Integrated Trials on the main mock up, where both the in cell team and the out cell team worked together as an integrated unit just as they would do on plant to not only train the operators, but also to develop and prove the procedures and prepare Operating Instructions. These trials involved testing the Pull/Push procedures as well as drilling operations, tested various fault scenarios and their recovery, and were made as realistic dress rehearsals as possible, e.g. with the out cell team wearing protective suits.

Originally both the in cell team and the out cell team consisted of a team of four personnel each: a team leader, deputy team leader, mechanical technician and electrical technician. For the second process line the team sizes were increased to 5 each to provide an element of increased flexibility.

By December 2002, the original project target of having the equipment ready to deliver to site by the end of the year had been met, and in March 2003 the replacement operations on Line 2 were successfully completed to programme in a six week period.

The original project intention had been to undertake the replacement operations on Line 1 no later than a year after Line 2. During this intervening period the team were to be retained to keep the equipment fully operational and in a condition where it could be delivered to site at short notice if required.

However, due to production reasons, plant delayed the replacement operations on Line 1 until 2006. Due to the length of this intervening period, most of the original team were disbanded and the equipment was put into long term storage.

The start of 2006 saw new team members recruited and the equipment taken out of storage and recommissioned. After the new team had undergone a period of training, including one Integrated Trial, the equipment was delivered to Line 1 in November 2006 and once again the replacement operations were successfully completed to programme in a six week period.

WORKING ENVIRONMENT ON PLANT

The in cell sections of the TWCs are located inside a C5/R5 cell where man access is prohibited due to the high radiation and contamination levels. Thus all in cell operations had to be performed completely remotely. In front of the working area was a lead glass window through which operators could directly observe proceedings in addition to using purpose built CCTV Pan and Tilt cameras.

Directly above the cell window were two electro mechanical Master Slave Manipulators (MSMs), which were used to assist the remote operations by performing tasks such as deployment of some of the equipment and connection of umbilical cables. However, because of the unusual nature of the tasks to be performed, the MSMs had only limited access and manoeuvrability in the specific work area. In addition, the calciner frame above the work area further obstructed direct access with the MSMs and in cell crane.

One of the original design specification requirements was that, because of the high contamination levels inside the cell, once equipment was deployed it could not be retrieved for decontamination to permit repairs or maintenance. Hence all in cell equipment had to be maintained to a very high standard with high levels of reliability prior to deployment. Because of this, three sets of all in cell equipment were manufactured: one set for Line 1, one for Line 2 and the third set was regarded as spare in case of in cell failures.

All the in cell equipment was deployed into cell by means of the normal plant import route i.e. through the C3 Module Change area (where it was finally tested) before committing it to the C4 Hoist Park and then deployed into the C5 cell using the in cell polar crane.

Umbilical power and service cables and air hose were posted through small diameter wall penetrations above the cell window and connected to the in cell equipment using the installed MSMs.

The drilling rig was installed in an area known as the induction room (which was temporarily re classified as a C3 area once drilling operations had started) on the other side of the cell wall to the in cell operators. The operators of the drilling rig (Out Cell team) had to dress in protective suits and wear full face respirators when entering this area to manually adjust the drilling rig, but controlled the actual drilling process remotely from a console located in an adjacent C2 area.

It was essential during the drilling operations that both the in cell and out cell teams were in constant communication, and this was achieved by means of a dedicated headphone system connected between the two control consoles.

TASKS TO BE PERFORMED ON PLANT

The main operations to be performed on plant can be divided into 4 main phases:

Removal of the TWC in cell sections

Removal of the in cell sections of the existing Through Wall Crossings was achieved by remotely deploying a hydraulically operated shear tool to cut through the copper pipes at each end. A clamp assembly mounted on the end of a purpose designed and built hydraulically operated manipulator was then used to clamp, rotate and pull the TWC off its key on the central support bracket.

Once the manipulator had rotated the removed TWC towards the cell window, it was picked up by the in cell crane to permit transfer to the Break Down cell for size reduction and waste disposal.

Drilling operations

The aim of the drilling operation was to drill out the existing holes in the in wall sections of the Through Wall Crossings increasing their diameter. This was in order to cater for the design of the new TWCs, which consisted of straight copper pipes.

Pull/Push recovery strategy

Only if the drilling operations on plant had been unsuccessful (for example due to drill bit failure, drill shaft misalignment, blockage formation, or unexpected behaviour of the asbestos based cement etc) would the recovery strategy known as Pull/Push have been resorted to.

This involved the complete removal of the existing in wall section of a Through Wall Crossing and its replacement with a new in wall section with larger diameter holes for the new copper pipes.

Deployment of the new TWCs

Once all the in cell sections of the TWCs had been removed and all 14 holes had been drilled out to the larger diameter, the new copper pipes could be pushed from the induction room straight into position in the cell.

DESCRIPTION OF IN CELL EQUIPMENT

The main in cell equipment can be considered as a number of discrete work packages:

Manipulator

The manipulator was a purpose designed and built 4 dof hydraulic system using demineralised water as the hydraulic medium. The primary purpose of the manipulator was to clamp and then pull the Through Wall Crossings off their central support bracket, once the copper pipes had been sheared. Fig 2 illustrates the manipulator in one of the full scale inactive mock ups.

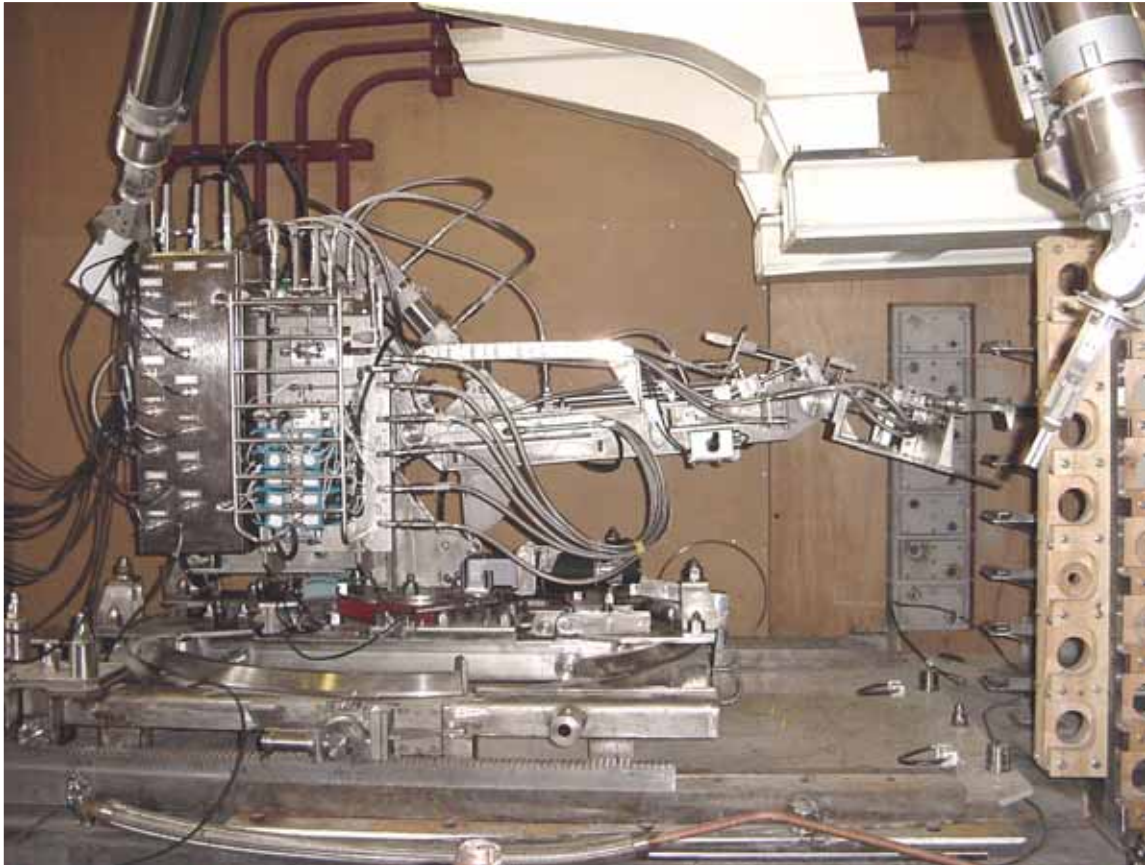


Fig. 2. Manipulator inside inactive mock up of cell

The manipulator had the following motions:

- arm raise and lower
- arm extend and retract
- tool head tilt up and down
- manipulator rotate

Manipulator translation backwards and forwards was provided by clamping it on top of a piece of plant equipment, the melter trolley, and driving this by means of its normal drive mechanism, i.e. a standard in cell screwing machine.

Although the primary functions of the manipulator were to clamp and remove the TWCs and the positioning of the vacuum system hose, it had to be originally designed with a high degree of flexibility and versatility so it could cope with a wide range of other tools and tasks which may possibly have been required.

The end of the manipulator arm was fitted with a simple modular mounting feature so that the different tools and workheads could be quickly and easily connected and disconnected from the arm using the installed MSMs and in cell crane.

At the start of the project there were a number of significant design specification requirements stipulated by the plant:

- The hydraulic medium must be demineralised water as leakage of conventional hydraulic oil or water glycol mixtures was considered undesirable due to the risk of contaminating the downstream waste processes.
- The manipulator must be remotely maintainable, such that in the event of a major component failure, it could be easily removed and replaced with a new one using the MSMs and in cell crane. Thus all the hydraulic actuators, hydraulic valves, hydraulic pump and reservoir, manipulator rotate motor and even the manipulator arm itself could all be replaced remotely. This was facilitated by fitting electrical cables and hydraulic hoses with quick connect/disconnect couplings.
- Once all the in cell tasks were complete, to assist and speed up the size reduction and waste disposal of the manipulator in the Breakdown Cell, there was a requirement to be able to easily remotely disassemble the system into a number of modular components. These could then be directly transferred into MA waste containers without any further size reduction.

A certain degree of redundancy was built into the system for example by providing a spare pair of hydraulic solenoid valves. This back up could then be used to drive any actuator once the MSMs had simply swapped the hydraulic hoses over.

The manipulator was fitted with a number of limit switches, pressure sensors and level switches to enable the operators to monitor and control the performance of the system during remote operations.

Pipe Shear Tool

The shear tool used a proprietary double acting pedal cutter to cut through the copper pipes on either end of the Through Wall Crossings, and was hung off the in cell crane to drive it into position with the MSMs. Due to the limited access of the crane to the back wall of the cell and because of obstructions such as the calciner frame, the shear cutter head had to be mounted on the end of a 4m long deployment tube. At the other end of the deployment tube was mounted the dedicated hydraulic power pack to drive the shear

cutter. Fig 3 illustrates the shear being positioned on one of the full scale inactive mock ups.

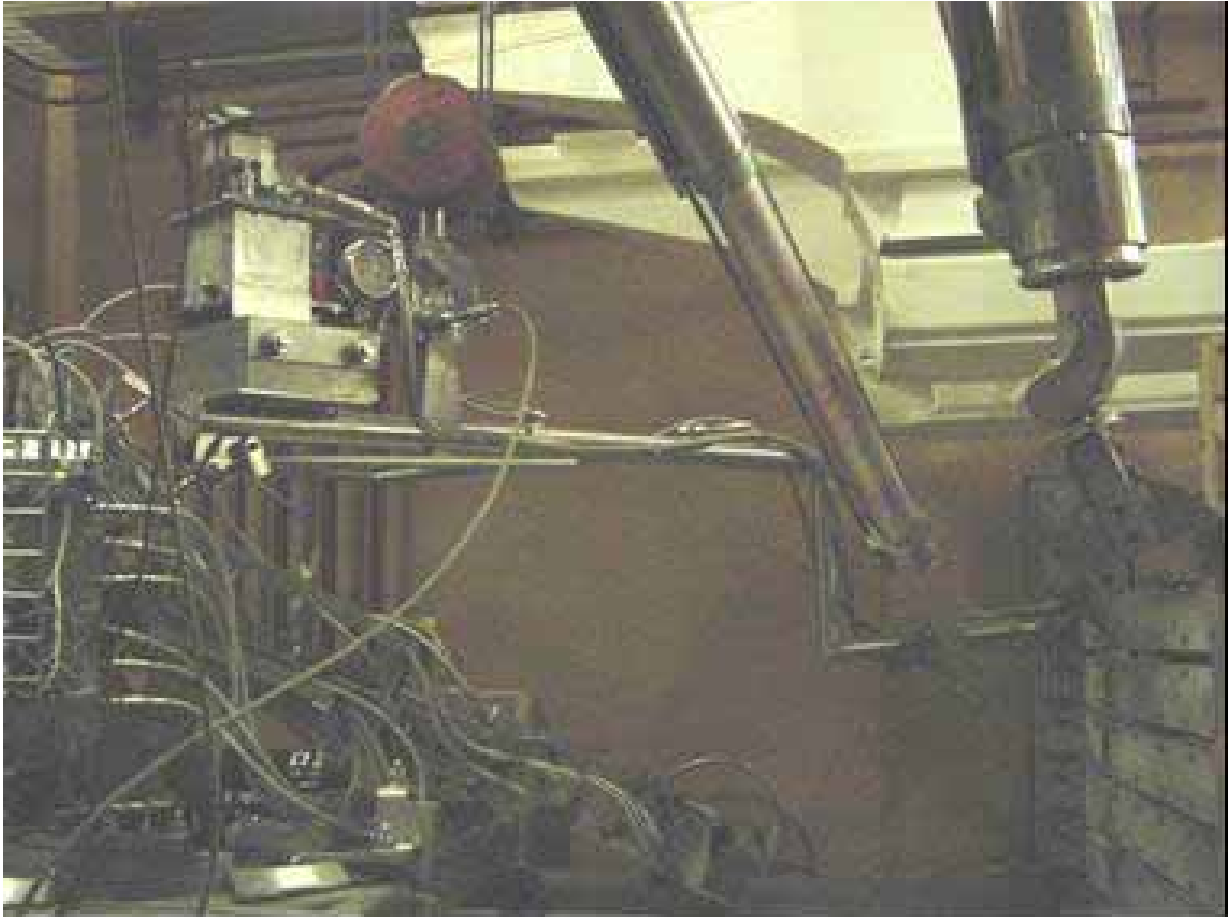


Fig. 3. Shear being deployed inside inactive mock up of cell

This power pack employed an air driven hydraulic pump capable of producing hydraulic pressure up to 10,000 psi, and again used demineralised water as the hydraulic fluid. As with the manipulator, the electrical signal cables for the solenoid valves and the air hose for the pump were passed through cell wall penetrations and remotely connected using MSMs.

The shear was also used for ancillary handling tasks inside the cell such as assisting with the pushing of copper pipes and push rods into the cell.

Clamp Assembly

The clamp assembly was the primary workhead to be mounted on the end of the manipulator arm, and can be seen in Fig 2. Its purpose was to clamp and support the cut Through Wall Crossings, whilst the manipulator dragged them off the central support bracket.

It comprised two bottom forks and two upper clamp arms which were hydraulically operated to clamp the Through Wall Crossing. The workhead was cleverly designed such that the clamping action also caused a rotation of the TWC causing it to lift off its key on the central support bracket

The head was also provided with an Emergency Recovery feature which enabled the clamp arms to be released by spring pressure if the release pins were activated by an MSM. This would enable the manipulator to be safely recovered if there had been a hydraulic failure whilst the arm was clamped onto a TWC.

Vacuum system

A proprietary 3 motor vacuum system was used inside the cell to collect the dust and swarf from the drilling operations. It was modified slightly in order to permit remote replacement with MSMs of the filter bags and pre-filter collection pots.

The collection shroud at the end of the vacuum hose had a mounting feature to enable it to be fitted to the end of the manipulator arm, which was then used to accurately position the shroud against the hole being drilled. A camera fitted above the shroud assisted in this accurate alignment. 4 different types of shroud were developed to cater for the various drilling options that could be selected.

Control System and in cell cameras

Operation of all in cell equipment was controlled by one purpose designed and built console, fitted with a variety of push buttons, switches and displays to enable the operators to fully monitor and control the equipment.

The design of the control system was deliberately kept simple with a minimum of interlocks or software control. Operation of the arm itself by trained operators was on a simple joint by joint basis with individual joint motion selected by means of key switches and push buttons. Both the in cell and out cell control consoles were linked such that activating the Emergency Stop on one panel would safely shut down both the in cell and out cell equipment.

Specially designed and built lightweight Pan and Tilt CCD cameras were deployed inside the cell to assist in remote operations alongside the normal plant radiation hardened cameras. The Pan and Tilt cameras were operated from a dedicated control console which enabled various views to be selected, recorded and sent to the Out Cell team. Although the Pan and Tilt cameras were only chip or CCD cameras they stood up to the radiation reasonably well and produced good quality pictures alongside the rad hard plant ones.

Reciprocating Saws

To cater for certain fall back scenarios, e.g. if the shear had failed or the copper pipes could not be pushed out, two different types of reciprocating saw were designed and built.

Although these both used the same type of electrically powered propriety reciprocating saw, one was designed to cut the pipes at the back wall of the cell and was mounted on the end of the manipulator arm, whilst the other was designed to cut the pipes near to the cell window and was hung off the in cell crane. Both types of saw were fitted with removable blades that could be replaced remotely upon failure.

Both saws were powered by remotely connecting their cable to a junction box on the end of the manipulator arm, and could cut through a copper pipe in approximately 4 minutes.

Pull/Push Workheads

A variety of other purpose built tools for the end of the manipulator arm were developed for the fall back strategy of Pull/Push. These included the

- hydraulically operated Tie Bar Removal Tool designed to grip and withdraw tie bars from the in wall section of the TWCs,
- the hydraulically and electrically operated Chisel designed to break up the in wall section of the TWCs,
- debris trays to collect the individual bricks of the old TWCs as they are pushed into cell and lead shield plates to provide shielding to the Out Cell team when the in wall section of the TWC is pulled back out into the induction room.

DESCRIPTION OF OUT CELL EQUIPMENT

The drilling rig (see Fig. 4.) was based on proprietary drilling equipment, but modified to enable it to be operated remotely from a control console in an adjacent room. In order to minimise the potential spread of contamination inside the induction room, the drilling rig itself was housed inside a PVC enclosure.



Fig. 4. Drilling Rig inside inactive mock up of the induction room

Once the drilling rig had been bolted to the floor of the induction room, the position of the drill head and cross slides could be adjusted to align the drill shaft with all of the 14 hole positions in the cell wall. Gross alignment motions in the vertical and horizontal directions were achieved by means of hydraulic drive motors mounted on the drill rig. Subsequent fine alignment of the drill shaft was achieved manually with operators entering the induction room, in protective suits, to adjust the rig. To ensure alignment and concentricity of a drill shaft and an existing hole in the wall, a laser alignment mandrel tool was inserted into the hole at this stage and shone onto a target in the drill chuck.

During this entry to the induction room, the operators also pressure tested the integrity of the seal plates and seal housings attached to the cell wall. These seal plates and housings were designed to maintain containment and prevent the blow back of any dust or swarf from inside the wall back out to the induction room. Also, to encourage this transfer of dust and swarf into the cell, two compressed air feeds were supplied to the seal plates and housings: one to send air down the centre of the hollow drill shaft and the other between the outside of the drill shaft and the drilled hole. In addition the cell ventilation system and the vacuum mounted on the end of the manipulator further encouraged the flow of particles towards the cell.

To further minimise the risk of spreading contamination, once a drill shaft had successfully drilled through the wall, rather than withdrawing it back into the induction room, it was left in the hole, and the seal housing was capped off. Thus 14 drill shafts were required to complete the task, and once all 14 holes had been drilled, the redundant drill shafts were then pushed into cell by the new copper pipes and collected by the manipulator for waste disposal.

The preferred option (once the in cell portions of the TWCs had been removed) was always to push the sections of copper pipe remaining in the cell wall through into the cell with push rods. This would then have required the drilling of just the asbestos based cement material and not copper as well. However as it was uncertain at the start of the project just how loose the copper pipes were in the cell wall, drill bits and procedures had to be developed for drilling both the asbestos based cement alone and asbestos based cement and copper pipes. Fortunately, on both Lines 1 and 2, all the pipes were successfully pushed into cell, and thus only the asbestos based cement had to be drilled.

DESCRIPTION OF PULL/PUSH EQUIPMENT AND PROCEDURES

As stated previously, only if the drilling operations on plant had failed would the fall back recovery strategy known as Pull/Push have been resorted to.

For this the drill rig main framework in the induction room would have remained, but been modified by replacing the drill head and shaft with a pulling plate, and attaching a glove box assembly between the front end of the rig and the wall.

Whilst the manipulator held a lead shield plate against the wall in cell, the drill rig would then have been used to pull the old in wall assembly of the TWC back out into the induction room until either the radiation levels became prohibitive or half the wall thickness had been withdrawn. Operators inside the induction room would then have dismantled the exposed portion of the TWC, block by block, inside the glove box, bagging out the individual blocks.

Following this, a new TWC assembly (with larger diameter holes for the new copper pipes) would have been used to push the remaining section of the old TWC back into the wall. Once the tie bars in this old portion had been pulled into cell by the Tie Bar

Removal Tool on the end of the manipulator arm, the individual blocks could be pushed further into cell and collected on a debris tray held by the manipulator. And finally the new TWC would be pushed fully home into its operating position ready for the new copper pipes.

Obviously this option was not preferred over drilling, and was always considered a fall back, because of the increased manual intervention required, greater risk of contamination spread, the issue of creating a temporary void in the cell wall and uncertainty over the actual ease of being able to physically move the old TWCs within the wallbox.

CONCLUSIONS

The initial phase of this turn key project for Nexia Solutions Ltd successfully designed and developed a suite of innovative remote intervention equipment on time and cost to a challenging programme duration of 18 months. In order to minimise cost, where possible, designs were based on proprietary equipment, which was subsequently modified for remote operations. As cost and in-cell equipment reliability were primary factors, the project philosophy was to keep the kit as simple as possible and rely on skilled operators to deploy it.

Extensive operator training on full scale mock ups enabled a highly motivated and skilled integrated team to be developed, whilst allowing rehearsals of all the possible fault scenarios and their recovery strategies.

The second phase of the project saw the equipment successfully used in two separate campaigns to modify the two process lines on plant. Again on both occasions the programmed target durations of 6 weeks for the shutdown work were achieved.

On plant operations were performed safely on both process lines without any significant hitches. The equipment performed well, and minor issues encountered were easily resolved by means of the flexibility of the procedures and versatility of the equipment that had been developed for the project.

As each batch of 14 holes on both process lines were successfully drilled, none of the pull/push equipment was required. And as both manipulators performed successfully inside the two cells, the third one was not deployed and is now available for possible future work.