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Fit For Purpose Design For Remote Operations: Handling The Hot Potatoes

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1. Introduction

INTRODUCTION BY GARY BUTLER, SENIOR MECHANICAL ENGINEER, AQUILA NUCLEAR ENGINEERING LTD

I am a Senior Mechanical Engineer for Aquila Nuclear Engineering Ltd and a designer of equipment and hot cell facilities. This technical paper provides an insight into hot cells from Aquila's point of view.

Remote handling must be employed in a wide range of situations where more convenient methods of operation are unsuitable due to the need for biological shielding or containment. Working remotely can readily be achieved by various means, however, they typically require concessions to productivity, versatility and user operability. Solutions are available which mitigate these drawbacks, but they can be costly and complicated to implement, particularly when considering existing facilities or limited/single-use campaigns. How do you balance these conflicts to find a fit for purpose solution?

Aquila Nuclear Engineering is an engineering design company providing bespoke solutions for the nuclear industry specialising in remote handling, shielded facilities, containment, and radioactive material packaging and transport. In delivering these projects, the engineering team frequently develops remotely operated equipment tailored to the needs of the user and limitations of the facility.

This presentation will consider three case studies, looking at what fit for purpose design means for three very different applications.

2. Case Study 1

PIE CAVE RE-CONFIGURATION – NATIONAL NUCLEAR LABORATORY, SELLAFIELD SITE

This is perhaps a fairly straightforward hot lab example. A dedicated facility, fully equipped with posting, remote handling equipment and services, configured for a long-term campaign of post irradiated material examination.

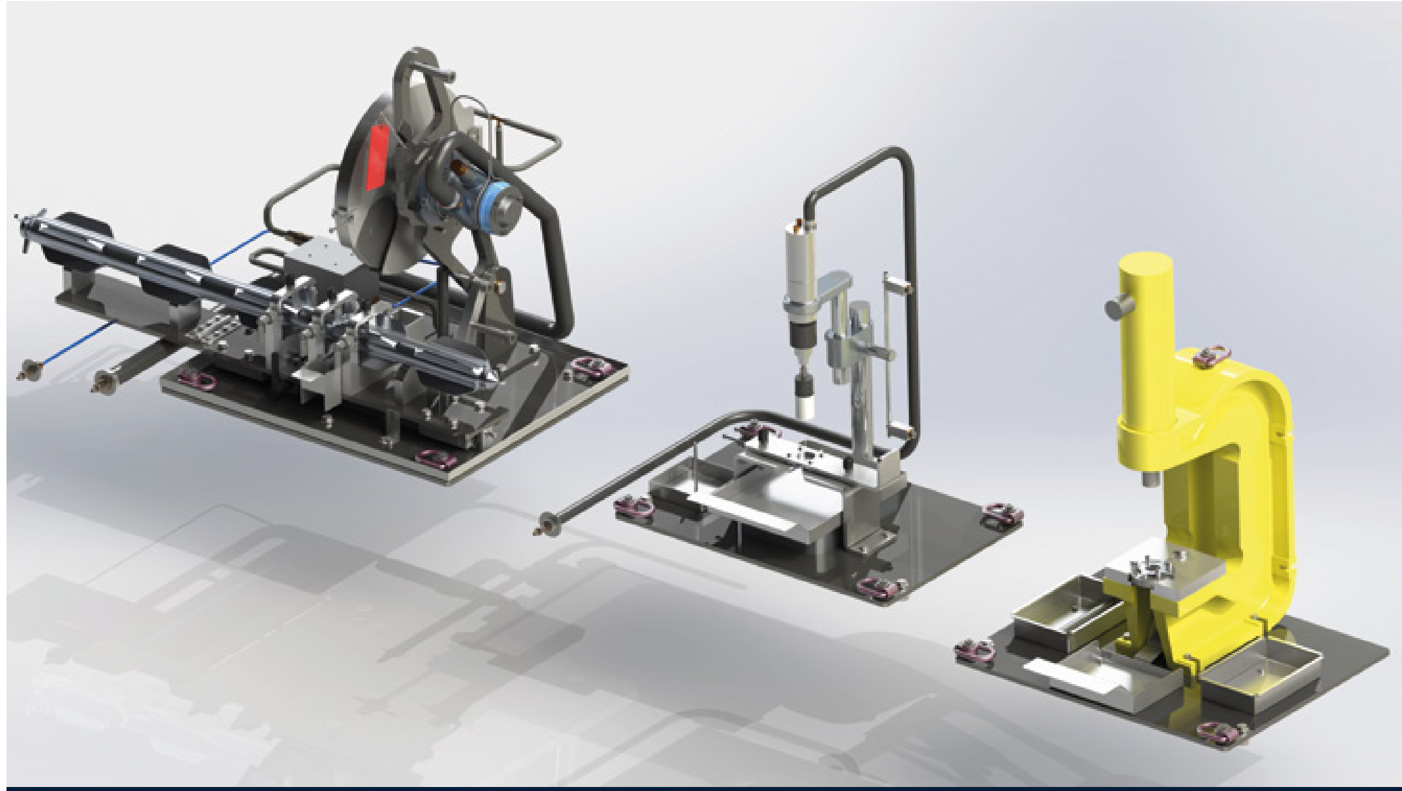

Figure 1: Case Study 1 - Three Size Reduction Rigs

HISTORY/BACKGROUND OF FACILITY

National Nuclear Laboratory (NNL) is a UK government owned but privately funded organisation that delivers a full range of research and technology to support the nuclear industry. NNL has hosted a number of UK Hotlab events in previous years.

NNL's high activity Windscale laboratory at Sellafield, offers shielded cell facilities to clients for processing and examination of reactor fuel and irradiated materials. These high activity caves are fitted with remote handling equipment and services, and may be decontaminated, emptied and refitted as required, to suit the requirements of the client.

PROBLEM/PROCESS

(Lifespan, throughput, operations, process, usage, operators training, remote handling etc.)

In 2017, Aquila designed and delivered a number of size reduction machines concerning the refit of one of these caves, to support a research project analysing fuel elements. MSMs (Master Slave Manipulators) are used exclusively to operate and maintain the equipment in a labour-intensive campaign expected to last 10 years.

Although the caves can be decontaminated and man entry arranged as part of the refit, this equipment had to be imported through an existing posting tray and installed remotely. Although this created a design challenge, it did ensure that installation doses were ALARP (As Low As Reasonably Practicable).

In terms of the process we were supporting, a Cutting Rig, Core Drill and Hydraulic Press were required to prepare samples for analysis. The Cutting Rig is used first to slice 5mm thick samples from various locations of interest along the length of the component. Samples are then transferred to the Core Drill where the core is removed and excess material discarded. Finally the separated core is loaded back into the Cutting Rig using a different work holding configuration to be quartered.

The third rig is a 20 tonne hydraulic press, used to strip the outer material from the core of discarded segments of the component, in preparation for disposal.

Due to the nature of the analysis being completed, it was critical that cross-contamination of samples was minimised. This means that during operation, frequent replacement of the cutting discs and core drills is required so the mechanism for fixing them had to be simple, secure (the cutting disc can run at 7000 rpm) and positively engaged.

FIT FOR PURPOSE SOLUTION

This mix of requirements guided the fit for purpose choices made during design. Aside from meeting the obvious functional and safety requirements, the design needed to focus on two areas of interest.

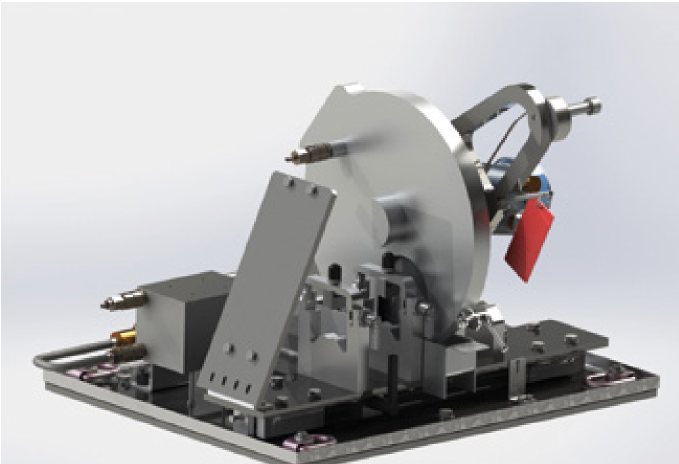

Figure 2: Case Study 1 - Import Configuration

Firstly, the import route and installation restrictions steered Aquila towards ‘plug and play’ equipment. Each of the rigs had to be designed to fit within the posting tray envelope and, with the exception of one item on the Cutting Rig, it was possible to simply position them and make connections to services using quick connect couplings.

The Cutting Rig appears relatively simple, a mark of good design, and not as though it has been compacted into a very small space. However, this is the result of the very careful selection of COTS equipment and refined cutting arm geometry. One minimal installation requirement remained, to unfold a carriage extension necessary to support the meter long components. Once imported, this hinged plate is unfolded and held in position under its own weight with no fixings required.

The second, more prevalent, consideration for this project was the long-term labour-intensive usage expected.

Figure 3: Case Study 1 - Simple, Robust Manually Operated Equipment

Individual simple, manually operated equipment was designed for each size reduction operation. Each rig had to be robust, efficient to use, and minimise day to day operator effort, with COTS items used wherever possible for reliability and adapted for remote operation and maintenance.

These modular units are simpler to design, operate and maintain. They are small enough to be posted out of the cave and potentially replaced if required, so while maintenance must be possible, the difficulty of the procedure could be balanced against the likelihood or frequency of occurrence.

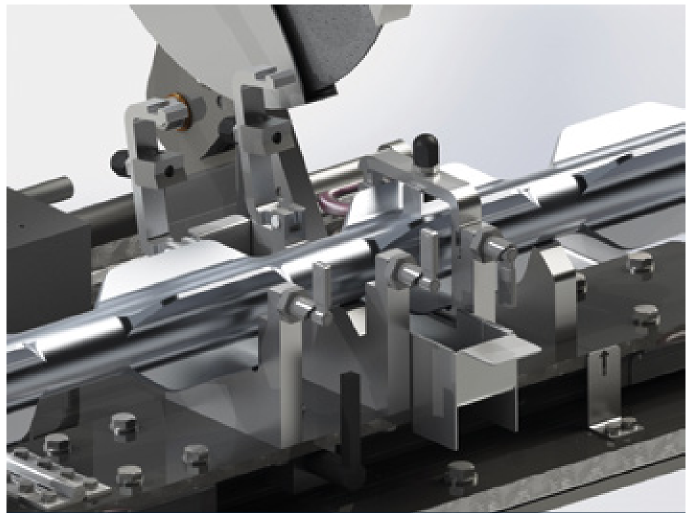

Figure 4: Case Study 1 - Typical MSM interfaces

All interfaces had to be simple and MSM compatible, especially those in daily use, and so were standardised as either square or hex 17mm across flats. This permits all the rigs to be operated with just MSM jaws or a single 17mm socket tool.

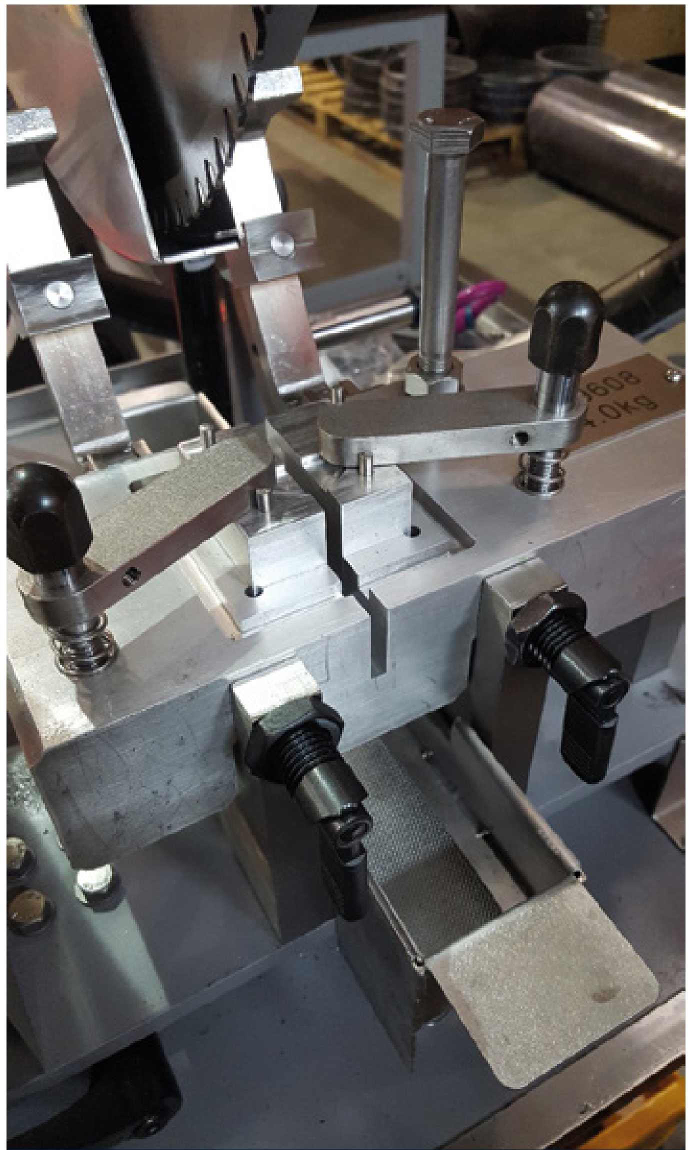

Figure 5: Case Study 1 - Clamp Block MSM Interfaces

This clamp block, fitted into the Cutting Rig when one of the samples is quartered, is a Poka Yoke design that will not fit in the incorrect orientation. Spring loaded pins (two black toggles in the foreground of Figure 5) required no MSM input to spring into the lock position, providing clear visual confirmation that they are engaged, and the block is correctly secured.

Clamp bars that hold the sample down are sprung loaded upwards and are simply swung into position against stop pins that ensure that they are in the correct position to engage with the sample. The operator need only tighten the clamps and visually confirm they are in between the pins to confirm that the sample is clamped in the correct position. These features helped with handling the relatively small 5mm thick Ø32mm samples, assisting with the distant view and lack of feedback available to the operators, and reducing the number and difficulty of steps required to operate the rig.

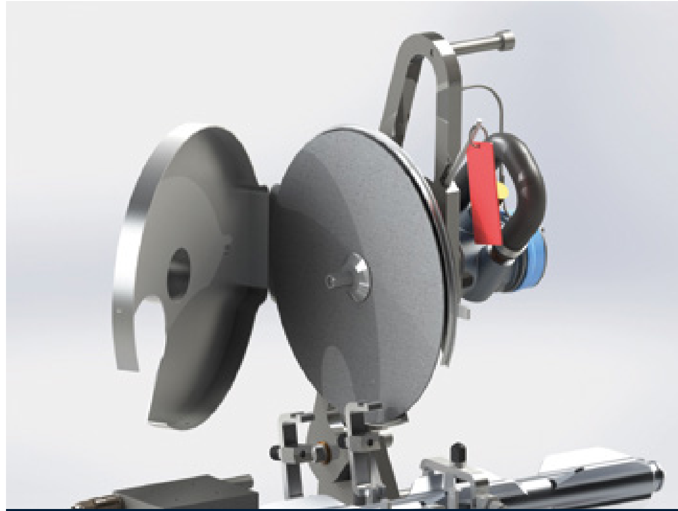

Figure 6: Case Study 1 - Blade Change Operation

Changing blades between cuts required opening the guard, inserting a gravity engaged pin to lock the motor shaft, and unscrewing a retaining nut on the spindle.

The blades sit on a generous close-fitting shoulder so they remain in place once fitted, and the spindle has a very long guide for the retaining nut. This ensured correct alignment to avoid damaging the thread and allows operators to concentrate on tightening the nut without having to also hold it in position.

SUMMARY

The result of these (and other similar) design features, is that all three rigs had no installation requirements. They can also be operated and maintained, with minimal effort, using only a single MSM.

3. Case Study 2

ACTIVE WASTE VAULT RETRIEVAL AND EXPORT – MAGNOX, BERKELEY

The second case study is a temporary hot cell constructed to assist in a decommissioning project. This is another dedicated facility to be operated remotely, but in contrast to the previous example, this was constructed for a short-term campaign and could be considered temporary.

Figure 7: Case Study 2 - Magnox Berkeley Power Station

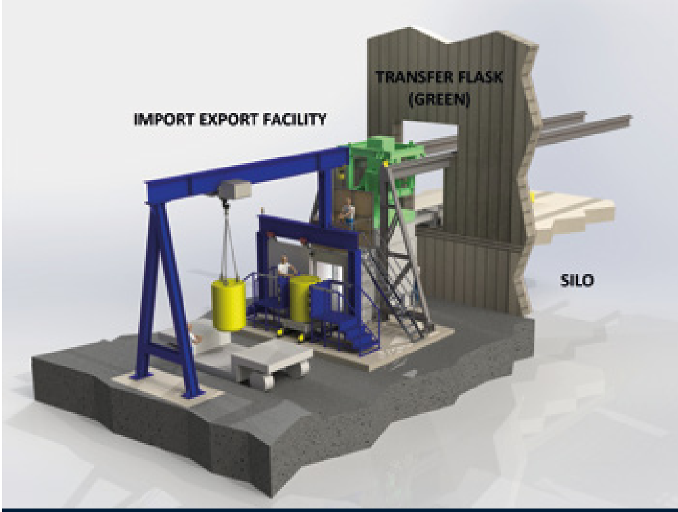

Figure 8: Case Study 2 - Silo, Transfer Flask and Import Export Facility

HISTORY/BACKGROUND OF FACILITY

Magnox Berkeley nuclear power plant generated power from 1962 through to 1989 and is leading the rest of the fleet as the first commercial power station in the UK to be decommissioned. The reactors have been sealed and are now in long term 'safestore' until 2074 but a number of challenges regarding ILW (Intermediate Level Waste) remain on site.

The AWV (Active Waste Vaults) are a series of underground concrete vaults that are currently storing a variety of waste accumulated during the lifetime of the two reactors and adjoining research laboratory. Emptying one of these required the creation of a temporary hot cell to safely package retrieved waste into shielded flasks for interim storage.

PROBLEM/PROCESS

(Lifespan, throughput, operations, process, usage, operators training, remote handling etc.)

In 2014, Aquila designed, manufactured and installed two packages to support the retrieval of controls rods from the silo 13m underground, and packing into 6,000kg DCIC (Ductile Cast Iron Container) shielded casks for long-term storage.

192 control rods, each Ø60mm and 8.5m long were size reduced in the silo by Magnox and loaded into baskets. The baskets were retrieved from the silo and transferred to an Import Export Facility using a 16,000kg Shielded Transfer Flask (Aquila's first work package) traversing on existing rails.

The Import Export Facility (Aquila's second work package) received an empty DCIC, prepared and positioned it ready to receive a basket from the Transfer Flask.

Empty DCICs are delivered on a transport and lifted onto a bogie using a crane integrated into the Import Export Facility. Access platforms allow operators to unbolt the lid and make preparations for import. When ready, the DCIC is moved into a shielded cell and a shield door closed behind it.

Now working remotely, operators remove the DCIC lid, inspect the condition of the lid seals and move the DCIC into the receipt position. Once a basket is loaded, the procedure is reversed with the DCIC only exiting the shielded cell once the lid is replaced.

Initial estimates suggested that the silo could be emptied in 35 baskets so the lifespan of the equipment was due to be very limited. Complexity in design, particularly EC&I was to be avoided in favour of procedural controls for operators, who understand what they are doing.

Similarly, recovery and breakdown mechanisms were never expected to be used and could be difficult provided they were achievable.

FIT FOR PURPOSE SOLUTION

In designing the solution, the focus moved away from regular operation, minimal effort and longevity, as in the previous case, to a low tech more agricultural approach. Safety and functional requirements still had to be complied with, but through close work directly with the end user and safety case author, Aquila was able to address them in a pragmatic way.

Manual control was the preference, and human effort was utilised wherever it was appropriate, starting with the shielded cell door.

Figure 9: Case Study 2 - Shielded Cell Door

This door weighed 7,000kg and was suspended from carriages running on structural steel that formed the support structure for the building crane. The door was made from laminated mild steel plates bolted together, the simple construction allowed it to be generously oversized compared to the cell. This made the door position less critical, regarding shielding integrity, and it was fitted with rubber buffers at each travel extent acting as position stops.

Movement of the door was by a drop chain, which was integrated in to one of the two COTS carriages. The provision of an established solution reinforcing that it was 'fit for purpose'.

Figure 10: Case Study 2 - DCIC Lid Removal

Once the DCIC is inside the shielded cell, the lid is removed by lowering an extension bar through a hole in the roof and screwing it into the lid. This is subject to some 'feel' on the operator's part to know when it is fully engaged, but it is made positive by design and cameras provided for visual confirmation.

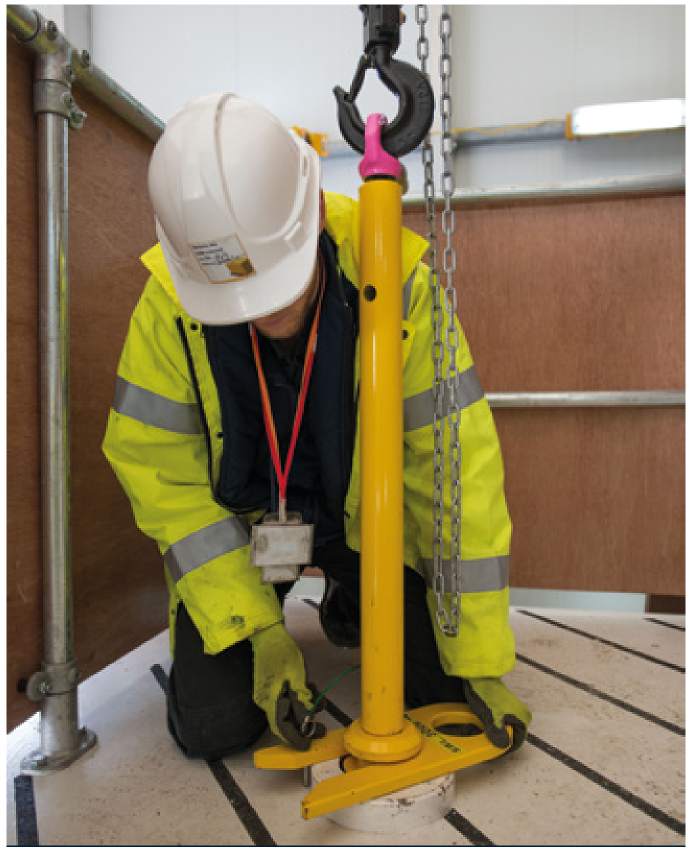

Figure 11: Case Study 2 - DCIC Bogie

The lid (weighing around 3,000kg) was hoisted up using a suitably rated manual chain hoist and a very basic locking plate fitted around the lid lifting feature so there was no suspended load. Again, the use of COTS equipment here helped to confirm that the operation and design were fit for purpose.

Figure 12: Case Study 2, DCIC Bogie

The final feature is the DCIC Bogie. This was required to move the casks between import (as shown in Figure 12), de-lidding and basket loading positions. The bogie ran on rails with four wheel blocks. A chain drive unit, capable of pushing and pulling the bogie, is located at the back of the cell and is fitted with a manual hand wheel.

Figure 13: Case Study 2 - DCIC Bogie Operator Position

Gearing was designed to suit human factors recommendations on operator effort and moving the 6,000kg flask required minimal effort. It took some time, travelling the full length of the rail required around 100 revolutions taking a few minutes, but these operations were not time sensitive and throughput was unaffected.

Compliance was designed into all of the DCIC interfaces so that accuracy and fine control was never necessary. Positioning was achieved using limit switches and lights at the operator station, with cameras again included for visual confirmation.

SUMMARY

The project was considered very successful and won an award from the NDA (Nuclear Decommissioning Authority). Following nine months of successful operation, the plant is no longer in use. In total, 11 DCICs were loaded (a third of the initial estimate) and the silo emptied of waste.

4. Case Study 3

LEGACY FACILITY DECONTAMINATION AND DECOMMISSIONING – GE HEALTHCARE, AMERSHAM

The final case study is an unusual case. This is a very old hot cell facility that is currently being decommissioned with limited knowledge of the plant, or what it contains. This means that solutions are reactive and normally required quickly to address issues, as they are uncovered.

Similar to the previous case study, many of these tools may be considered temporary, but shouldn't be considered disposable. Every item introduced to the facility adds to the total waste burden.

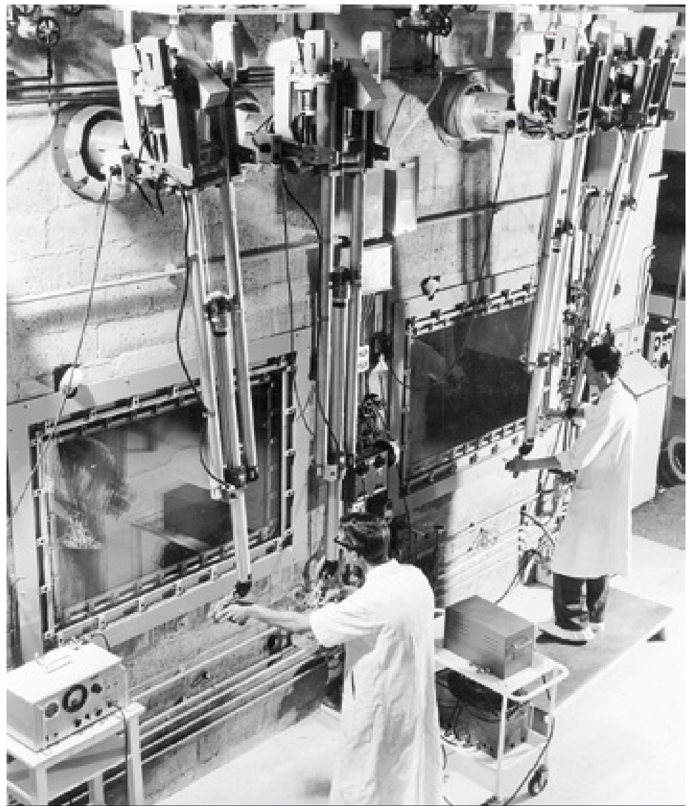

Figure 14: Case Study 3 - GE Healthcare Amersham Senior Caves

HISTORY/BACKGROUND OF FACILITY

The Senior Caves facility in Amersham was constructed in 1957 on what was then a UKAEA (United Kingdom Atomic Energy Authority) site manufacturing radioactive materials for peacetime uses in medicine, scientific research and industry. Originally intended to purify fission products in support of site processes, an accident in 1962 resulted in widespread Cs-137 contamination preventing purification. The plant was used to produce Cs-137 sources until 1964 and in 1966 an attempt to decommission one of the cells resulted in another leak and further spread of contamination.

PROBLEM/PROCESS

(Lifespan, throughput, operations, process, usage, operators training, remote handling etc.)

Returning to the facility in 2010 to begin decontamination and decommissioning, GE Healthcare started with no lights, services or remote handling equipment, and solid steel shields in front of leaking Zinc Bromide windows meaning no internal view.

Figure 15: Case Study 3 - Senior Caves Internal View

Figure 16: Case Study 3 - Senior Caves Internal View

Over the course of the last six years, Aquila has supported GE Healthcare with a variety of novel remotely operated equipment, reacting to the unique problems as they have been uncovered. Due to the single use nature of much of the equipment, trials and close collaboration with the plant operators has been vital to maintain decommissioning progress and minimise secondary waste generation.

Figure 17: Case Study 3 - Multipurpose Port Bung

After initial work to establish a safe route into and out of the caves complex, work began on decontamination.

Figure 18: Case Study 3 - Survey Trolley

Tools have been varied and included simple trolleys, brushes and rakes for clearing out inaccessible transfer tunnels between cells.

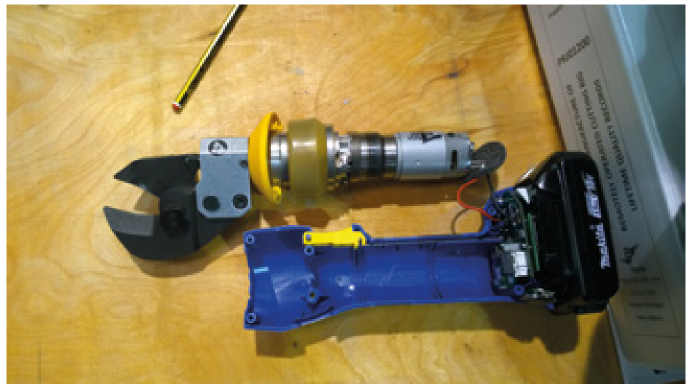

Figure 19: Case Study 3 - Hydraulic Shears

Tools deployed to complete specific tasks, like these cordless hydraulic cable cutters used for stainless steel instrument lines, were adapted for MSM operation.

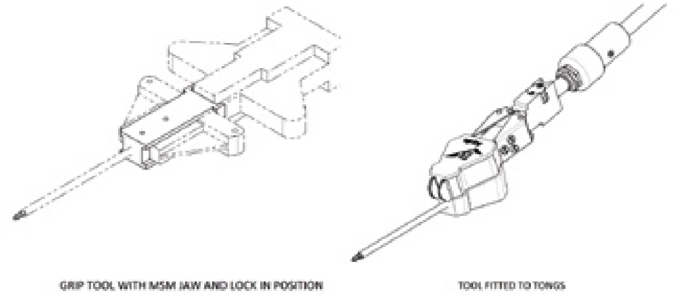

Figure 20: Case Study 3 - 3D Printed MSM/Tong Tools

Low cost, standard handles for MSM and tongs, allowing GE Healthcare to simply customise or make their own tool set.

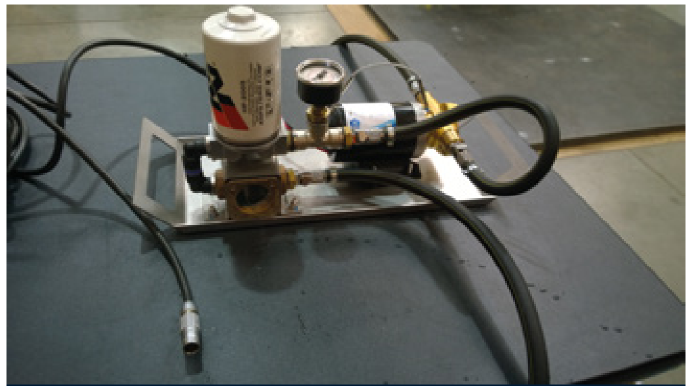

Figure 21: Case Study 3 - Zinc Bromide Recovery Rig

A miniature filtration and pump rig to circulate and filter Zinc Bromide as it is decontaminated through precipitation and ion exchange.

One tool in particular has proved to be particularly effective. Following a period of research and trials, the brief was to develop a proof of concept miniature grit blasting rig with integrated vacuum retrieval for use inside the caves, for removal and collection of surface contamination.

Figure 22: Case Study 3 - Vacuum Blasting Nozzle and Blast Pot

Vacuum grit blasting was chosen because it is capable of aggressive material removal and is simple technology that could conceivably be adapted and deployed in an ageing hot cell, without compromising its integrity. It also has the benefit of collecting the removed material.

This facility has very limited services and handling equipment so the first step was to modify some existing COTS equipment and functionally prove the concept using a physical mock-up of one of the containments. Everything must be imported at one end of the caves complex, transferred manually through tunnels to the caves, and connected remotely using tongs.

The mock-up provides operators and designers the chance to handle the equipment and experience the process, providing invaluable feedback to be included into the finished design. Most of the changes concerned what could actually be achieved in this unique environment where each cave has only a single MSM and camera.

Once these refinements had been made, the equipment was designed and built, using many cost-effective COTS components. These were modified, where necessary, to suit the handling requirements but the core of the equipment remained unchanged. This use of modified COTS greatly reduced design development and commissioning time.

Figure 23: Case Study 3 - Vacuum Blasting Inside the Caves

SUMMARY

The equipment, which was originally designed as a proof of concept that was expected to be replaced with a larger more capable unit, has now seen extended use in the heavily contaminated caves, reaching into areas it was never expected to operate. Although a slow, labour-intensive process, progress is being made and contamination is removed from the facility each time the grit is replaced.

And a final bonus, having a vacuum unit inside the caves has also been capitalised on by attaching disposable canisters instead of grit blasting equipment, providing operators with a vacuum cleaner. Invaluable when you have only one hand.

5. Summary

FIT FOR PURPOSE DESIGN FOR REMOTE OPERATIONS.
Although each of these environments and applications were quite different, there are common threads running through all of the designs.

COTS EQUIPMENT - DON'T REINVENT THE WHEEL
Use of COTS equipment proved pivotal in each project for different reasons. The supporting knowledge that comes from a specialist supplier results in better selection of components; reducing the design effort required and increasing reliability.

Adaptation of COTS components, either by the manufacturer or otherwise, allows rapid development keeping useful functionality that already exists while making it suitable for the application.

Whether modified or not, the reassurance obtained from proven components makes substantiation much easier in an industry where novel designs and technology are closely scrutinised.

KEEP IT SIMPLE – DESIGN OUT COMPLEXITY
When you do have to start from scratch, it is always harder to design something to be simple. All of these case studies aimed to have minimal automation, EC&I systems, and actuation by manual means wherever possible. Of course, some processes will require these, but each should be viewed on a case-by-case basis and should not be used as a matter of course.

Manual operations, when they are appropriate, can significantly help to reduce complexity, especially when replacing drives and actuation. Human factors are well understood and we shouldn't be afraid to ask people to move.

Recurring use of gravity, springs and physical guides or stops not only reduce effort but provide security to reinforce procedural controls in the absence of control systems. Throughout, generous compliance is always favoured over fine control which makes commissioning and in-service maintenance far more time consuming and susceptible to minor variations.

And finally, simple can means less parts, less spares, and less secondary waste.

ENGAGE OPERATORS AND BALANCE EFFORT WITH FREQUENCY
As designers, we are aware of remote operation difficulty but are not truly experienced in it. We attempt to appreciate what can reasonably be achieved, and have to balance the likelihood of such tasks against economical design.

Too often, these issues come to light during testing or commissioning when the equipment already exists, making it difficult and more costly to change. Often the solutions or adjustments are basic and maybe trivial to the designer, but significant to the end user.

Changes must be proportional to the gains. Echoing the second point above, it is easy to start adding complexity to mitigate against a barely credible scenario, a 'once in a plant lifetime' occurrence. For this, we must ensure that it can reasonably be achieved, but not be concerned about it being difficult.

Engaging plant operators as early as possible helps inform these decisions and allows a far more accurate balance to be achieved. Mock-ups and practical experimentation is always invaluable and allows the flow of information and experience at the right time in the design process.

SUMMARY
By considering these principles as early as possible during the design phase, it was possible to significantly reduce cost, program and risk on these projects and provide fit for purpose solutions.

6. Acknowledgements

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