Diverse Solutions for Common Demands

A Tale of Two Facilities

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A. Abstract

As part of the UK governments' drive to enhance technical capability and expertise, there has been capital investment in both new and expanded research facilities.

Aquila Nuclear Engineering Ltd has been involved with the specification, design and supply of HOT CELL solutions for two facilities that have now been installed and commissioned:

- **A suite of Hot Cells at the new 'Materials Research Facility' at UKAEA, Culham Science Centre**

  The facility has been created to provide an academic and commercial facility for the examination and inspection of irradiated samples.

  The UK Atomic Energy Authority (UKAEA) is giving a presentation of the facility's capabilities at the HOT LABS conference.

- **End of Beam Line Target, Handling and Storage Hot Cells at the University of Manchester Dalton Cumbrian Facility**

  The Dalton Cumbrian Facility is an academic facility operated by the University of Manchester and is used to create radiation damage of target materials.

Through close collaboration with our clients, Aquila were able to assist in the realisation of both of these projects. Taking early ideas and concepts from client discussions, we utilised efficient CAD design techniques to develop, cost and present the concept facility design. Being able to present in a clear manner assisted in design development, enabling swift understanding from all parties, of the project requirements and ultimately resulted in swift design approval. Those same CAD techniques then enabled manufacturing to commence extremely early in the project programme, resulting in significant timescale savings. Through listening to the requirements and combining our extensive experience of delivering practical solutions, we were able to project manage, design and install fully functioning facilities. Through the design process we produced cost effective, robust solutions, utilising commercially available solutions where feasible and straightforward design evolutions where not.

B. New Research Facilities in the UK

As part of the governments drive to become a 'top table nuclear nation', it has set out a strategy to develop the UK nuclear industry. It has recognised that along with new build; 'The research community is also a key partner because of the significant engineering and scientific challenges that have to be addressed for new nuclear systems and their legacy.' (Government, 2013). As such, the government has launched the 'National Nuclear Users Facility (NNUF)', a collection of three complementary facilities; at the Central Laboratory of the National Nuclear Laboratory (NNL), the UK Atomic Energy Authority, and the Dalton Cumbrian Facility (part of The University of Manchester). The aim of these facilities is to offer the nuclear R&D community better facilities to conduct experiments on materials that are too radioactive for conventional laboratories.

C. UKAEA Materials Research Facility

Overview

The UKAEA Materials Research Facility has been established to analyse material properties of both fission and fusion based irradiated samples.

FIG 1. UKAEA MATERIALS RESEARCH FACILITY

The facility allows users to send samples in standard transport packages in preparation of nanoscale analysis. Within the facility's preparation hot cells, samples are unpacked, size reduced, encapsulated, polished and inspected prior to being transferred to a suite of analysis cells.

Within the analysis cells, samples may be subjected to a range of processes such as inspection through a scanning electron microscope, Dual-beam Focused Ion Beam Scanning Electron Microscope and analysis and measurement through a nano-indenter.

More detail of the facility will be presented at Hot Labs by Monica Jong from UKAEA. Contact details provided at the end of this document.

D. Aquila's Involvement with UKAEA

Aquila were initially approached by UKAEA in a consultation role to peer review the existing proposal for the facility. At that moment in time, the site of the new facility had been identified and the building concept and outline had been fairly well defined. The basic processes had been defined along with inventory limits, to define basic shielding requirements.

As our relations grew, we received more packages of work. Fairly quickly, we were asked to assist in generating the specification for the preparation hot cells. Through Aquila's many years of experience in providing bespoke engineering solutions for the nuclear industry, we quickly realised the opportunities for success and the pitfalls to failure of such systems. Through our collaborative partnership with UKAEA we quickly understood the motivations and processes required to deliver the project successfully.

E. Technical Overview of the Preparation Hot Cell Facility

UKAEA had themselves already carried out a lot of preliminary work regarding the facility. The basic processes were defined along with preliminary equipment lists. However, layout of the cells, particularly in relation to practical working arrangements, and practical methods of receiving and unpacking as yet unspecified transport packages, were still to be developed.

Biological Shielding

As stated earlier, UKAEA had conducted a preliminary cost analysis of the shielded structure in order to identify the most cost effective construction material. Lead produces the lightest and most space efficient solution, while concrete produces the cheapest solution. Steel offers a good compromise, as the cost is closer to concrete, but shielding efficiency allows for more efficient space utilisation. These positions were further amplified when the cost of floor reinforcement was considered. Fortunately for UKAEA, the MRF was a brand new facility and therefore floor loadings could be defined up-front and accommodated within the design of the building. As such, steel was considered to be the most appropriate material.

Having defined the material, the next question was 'how much'? UKAEA had looked at the anticipated supply of materials and after deliberation consolidated the requirement to a defined maximum single source of 3.75 TBq of ^{60}Co. Given their site allowable dose rates, this equated to shield walls of 350mm thick steel.

Receipt Cell

While the purpose of the facility was well defined, understanding how sources may be delivered presented a problem for the design – 'how to safely unpack a sample from an unknown container'? Aquila considered options and utilised their experience to devise a system whereby an inner posting package, of known dimensions – or at the very least, of known interface, could be sent out to clients for them to pack into their transport flask. This then allowed the 'sample removal from flask' process to be defined, but still left the 'open the flask' process open for consideration. For this, it was considered that a vertical flask was the most likely delivery scenario and therefore an independent hoist should be utilised to lift out a shielding plug to reveal the inner posting package. Final interfacing details of the attachment of the hoist to the shield plug would need to be considered on an individual basis, but suitable bespoke couplings could be designed and manufactured very easily if indeed they be required.

The size of the cell was always going to be a tricky compromise to make. Large enough to cater for whatever may be required, without costing more than was necessary. In the end, a working size of 2.2(W) x 1.8(D) x 2.1(H) was settled on, which allowed for a 1.6m wide aperture through the door – large enough to get a large Croft SAFSHIELD flask into the cell and unpacked.

F. End of Beamline Pelletron Accelerator Target Handling and Storage Hot Cells

Overview

The Dalton Cumbrian Facility is a state-of-the-art nuclear research complex where academia and industry collaborate on radiation science and nuclear engineering research. They offer sample preparation, materials damage, and post-irradiation characterisation capability. Materials damage facilities include a 5MV tandem ion accelerator and recently installed 2.5MV light ion accelerator.

They offer open collaboration with academic, industrial and government stakeholders, using a wide range of equipment. Of particular interest is their 5MV tandem ion accelerator, delivering to six beam lines with three high precision raster scanners, into two concrete vaults. One of the beam lines is equipped with a suite of hot cells to allow higher penetration and higher damage rate studies to be conducted. The hot cell suite consists of a target and handling cell.

FIG 2. DALTON END OF BEAMLINE PELLETRON ACCELERATOR TARGET HANDLING AND STORAGE HOT CELLS

The target cell is constructed with a borated HDPE inner neutron shield, a lead outer gamma shield and a steel support frame. To enable good access to the target chamber within, there are four hinged, interlocked shield doors.

The handling cell is constructed with an inner stainless steel liner, a lead outer gamma shielding and steel support frame. The cell features a lead glass window and a pair of tongs for manual manipulation of samples. A shielded storage facility within the cell allows up to 12 samples to be stored. A transfer mechanism allows hot samples to be safely retrieved from the target cell and a posting port allows the transfer of samples into a licensed transport package.

Further information regarding the site capabilities and opportunities can be obtained by Mr Kevin Warren. Contact details provided at the end of this document.

AQUILA'S INVOLVEMENT WITH DCF

Aquila were approached by DCF with a report that they had commissioned, 'Radiological Implications of High Current Operation', with a requirement to conduct a shielding study and assist in writing a User Requirement Specification (URS). The report outlined the planned activities to be carried out with the pelletron and suggested some initial shielding concepts. It identified typical sample materials along with anticipated activation products.

Aquila looked at the report and its' proposals and then considered the practicalities of engineering viable solutions. Given the requirement to be able to store samples, it was soon evident that the most practical solution was to conceive two adjacent hot cells – one for the target station (requiring prompt neutron and decay gamma shielding) and a separate, decay gamma only, shielded cell for handling, transfer and storage. Also, for the target station, it was considered preferable, both from possible neutron activation of the antimonial lead and a practical construction point of view, to fit the borated HDPE neutron shielding inside the gamma lead shielding, not outside as initially proposed.

These arrangements were quickly laid out in CAD to present to DCF. The issue of appropriate shielding material and basic construction details were again considered. In contrast to the UKAEA facility, the DCF was already operating when the hot cell requirement was instigated. As such, the decision process, which lead to the selection of steel as an appropriate shielding material for UKAEA, did not hold. Instead, since a floor loading limit was a significant influence, it was determined that lead would be the most appropriate gamma shielding material. Aquila's vast experience in the use of lead shielded hot cells, soon enabled an appropriate design to be developed. The shielding provision was a compromise between academic need, weight and cost. As many of the potential irradiations are unique, the anticipated radiation effects had to be ascertained by the use of Monti Carlo modelling to provide a level of assurance. The site also has existing licence arrangements which have to be maintained.

Of primary importance to the beam users, was good access to the target chamber and associated equipment around it. As such, access from both sides of the cell was desired and various door options were considered. Ultimately, given the layout of the beam lines, double hinged doors provided the best access scenario, but also presented construction challenges, such as providing appropriate structural support, while ensuring adequate shielding through the HDPE/lead composite door split.

G. Routes to Engineering Success

LISTENING TO CUSTOMERS' REQUIREMENTS

Without first listening, we cannot begin to understand. Aquila are proud of our engineering expertise and experience, but while we have long and varied experience of projects over a large number of nuclear sites, we do not, and could not, profess to be experts on your systems and processes.

Example, UKAEA: Engineering a cost effective modular design to enable expansion of the cells as future needs dictate.
Example, DCF: Engineering practical access to the target chamber within a neutron/gamma shielded facility.

UNDERSTANDING PRACTICALITIES OF DELIVERING ENGINEERED SOLUTIONS

This is where Aquila excels. The perfect process may not be achievable to engineer, or at least engineer economically. Understanding where appropriate compromise can be made, to least impact a process, while delivering appropriate cost or programme gains, are fundamental to our business.

Example, UKAEA: Manufacture of two discreet sub-systems independently and successfully combining them on site to reduce cost and programme.
Example, DCF: Engineering cells that can be assembled and proven at works, delivered virtually complete, yet fit through a restricted aperture, and are then easily re-assembled and commissioned to reduce the site labour and therefore programme and cost.

UTILISING PROVEN DESIGNS – KEEP IT SIMPLE, WHY REINVENT THE WHEEL?

It sounds obvious, but it is not a policy that is always understood or followed. Use of COTS (commercial off the shelf) components should be always be considered, since they offer cost benefits through economies of scale, in both implementation and maintenance. However, the nuclear industry often places demands that are not seen in wider commercial use. As such, over specification of COTS items can lead to unreliable and difficult to maintain systems. It is vitally important the failure mechanisms of any system are fully understood and considered during design, to ensure the appropriateness of all specified components. It should be noted that COTS items themselves are often configurations of smaller COTS items. Drilling down a level, can allow the cost benefits of COTS while maintaining the configurability of bespoke – key decisions early in design have massive impacts on the success or otherwise of projects.

Example, UKAEA: The main receipt cell door is necessarily large (30 tonnes) to enable a range of unknown flasks to be opened. This, inevitably, resulted in the creation of a bespoke design. However, in order to minimise risk and keep costs under control, COTS items were used where possible. In particular, use of proven COTS crane wheels took uncertainty out of design calculations and enabled a manual operation mechanism to be designed, simplifying control elements and reducing safety fears that would have arisen with a driven system.
Example, DCF: The transfer hatch gamma shield door, while being a bespoke design, leans heavily on proven concepts and configurations, developed over many projects – evolution and configuration not revolution.

KNOW YOUR STRENGTHS AND WEAKNESSES

We can't be experts at everything. It is important to focus on your strengths and understand when it is more appropriate to seek assistance from others.

Example, UKAEA: At Aquila we are used to ventilating hot cells. However, UKAEA required a complete active ventilation system, including plant room and stack. We immediately recognised the requirement to engage one of our partners, Hargreaves, to design, build and install the plant room, agreeing interfacing details for both the ducting and CE&I controls.
Example, DCF: As well as assisting in the development of a URS, Aquila were approached by DCF to conduct a shielding study. The nature of the study was not straight forward however, since it involved neutron activation of a range of materials, made up of many elements. This was a problem that required external expertise and so specialists, ARC (Abbott Risk Consulting), were engaged to conduct an MCNP analysis and report.

UTILISING CAD APPROPRIATELY USING MODULAR 'TOP DOWN' DESIGN METHODS

Modern 3D CAD systems offer tremendous tools and benefits to engineering designers … if used appropriately. A well-executed model allows designers to evolve their designs simply and effectively with minimal effort. Time spent at the front end of a job pays dividends later on, not just in detailed design, but also in manufacturing and assembly.

Understanding the job at the outset, and having a feel for how it may evolve, is key to setting up the structure and interfaces within the design. These are then 'flowed-down' through the design, such that changes automatically update the model in a controlled, predictable manner.

Using this approach allows for the development of concepts, which can then be presented to clients for discussion early within the project. Changes can be quickly invoked and a concept can then evolve into a scheme, to be further refined into a detailed design – always refining and improving rather than re-starting.

Example, UKAEA: Having a modular design for the steel shielding not only allowed for cost reductions by delaying the implementation of all of the cells, it also allowed for simplification of the design detailing and manufacture, by allowing multiples, or minor variants, of the same item to be manufactured. By concentrating early on, on the design of the shielding laminations, and flowing the design features through the model, the detailed design of the shielding panels were released to manufacturing very early in the project programme. This allowed 350 tonnes of steel shielding to be ordered within 5 weeks of the contract award and works assembly of the shielding within 3 months.
Example, DCF: Using a 'top down' approach to design allowed Aquila to disseminate major sub-assemblies to small design teams while confidently ensuring integration into the main build. This allowed for major reductions in lead time. In particular, it enabled key sub-assemblies to be procured from different countries, with confidence that they would fit together.

H. Bibliography

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I. Contacts

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