Aquila Nuclear Engineering Ltd

Design and Manufacture of HOT CELLS

Process is King

Prepared for 51st Annual Meeting HOTLAB-2014 at Paul Scherrer Institute Baden, Switzerland

21st -25th September 2014

Contents

A. Introduction to Aquila Influence Diagram 1
B. Introduction to Aquila 1
C. "Process is King" Hot Cell Design & Manufacture 2
D. Shielding 5
E. Containment, Isolation and Gloveboxes 7
F. Classification of Containments 7
G. Containment Assembly, Leak Testing and Flow 8
H. Conclusions 8

A. Introduction to Aquila Influence Diagram

Having been involved in the nuclear industry for over 30 years, I have first-hand experience in relation to many design and build projects.

The design and build of Hot Cells is one specialist area that greatly interests me. Hot Cell design and build always raises technical challenges which, with sound pragmatic engineering, can be delivered effectively to the client's satisfaction. At Aquila, we use the Aquila Influence Diagram to address all operational, Health and Safety and regulatory requirements. This methodology is used to help us develop the specification, design the cells around the equipment and manufacture a user friendly Hot Cell facility.

B. Introduction to Aquila

At Aquila, we focus purely on the nuclear industry, both nuclear power and nuclear medicines. In both these sectors we provide feasibility studies, project costings, prototype development, scheme design and detail design through to full manufacture, assembly and testing.

In both nuclear power and nuclear medicines sectors we operate in 4 principal areas:

• Shielded Facilities	In concrete-Steel and lead
• Containment Systems	Including gloveboxes-liners-isolators with in box process equipment
• Remote Handling	Including in box hoists-manipulators-robotics-tongs
• Transport Packages	Flasks-pots-Kegs-Vials

Our activities cover a number of nuclear specialist groups which include for example:

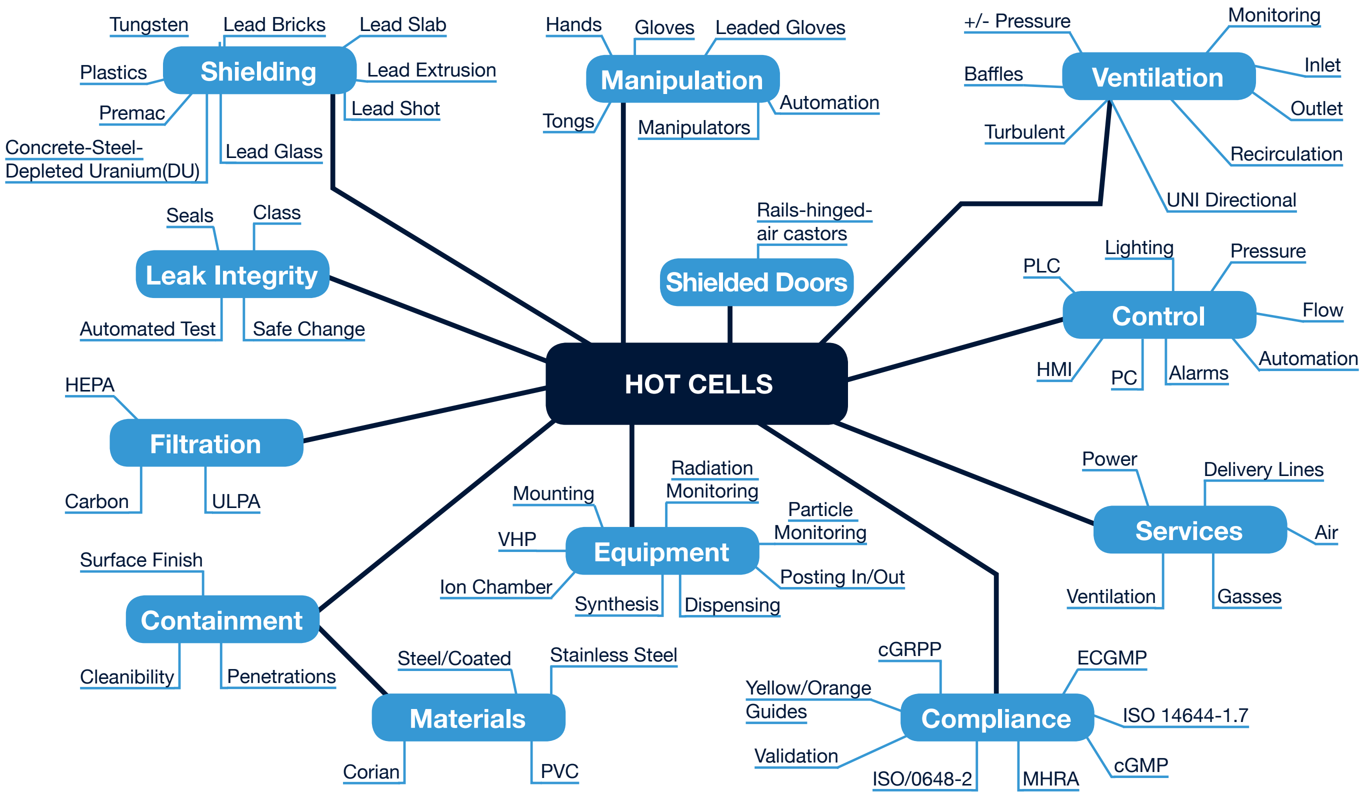
• Research Centres	Post Irradiation Examination and Material Test Cells
• Decommissioning Centres	Waste Retrieval, Assay, Size Reduction
• Plant Life Extension Groups	Remote Inspection and Repair
• New Nuclear Build teams	Liquor Sampling, Remote Filter Change Systems

C. "Process is King" Hot Cell Design & Manufacture

At Aquila, we like to get involved as early as possible in the project so that we can add value for our clients during the decision making process.

Although this is not always the case and we regularly receive invitations to participate in projects after the detail design has been completed by the Client.

However, when we are asked to participate early in the project we always use the Aquila Influence Diagram to start the production of a specification, working hand in hand with our client.



The Aquila Influence Diagram identifies areas which may be required to meet the Functional Requirement Specification (FRS) and Design Requirement Specification (DRS) provided by the client. The Aquila Influence Diagram covers both nuclear and nuclear medicines applications and includes principal subject areas such as:

- In Cell Equipment
- Shielding
- Containment
- Ventilation Philosophy
- Manipulation
- Control Philosophy

The range of process equipment located inside Hot Cells and containment can vary significantly. For example, the process can be dealing with:

- Gases
- Liquids
- Mixed phase or slurries
- Metals, plastic or cellulose

Therefore, the process equipment may include, equipment, pumps, valves and instrumentation and more specifically, key areas such as:

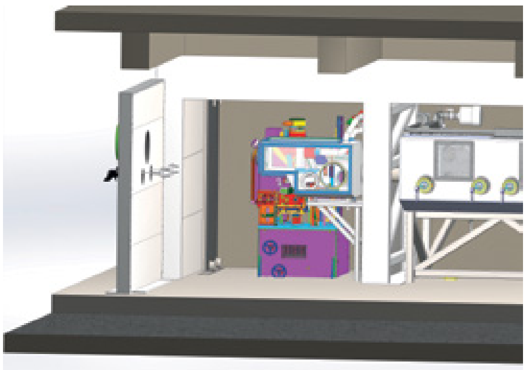
- **Dispensing & Synthesis system (particularly for nuclear medicines production)**

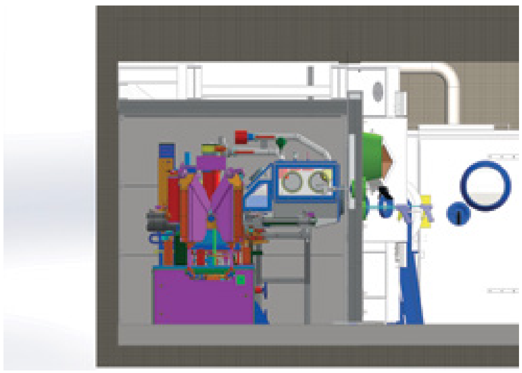
Images courtesy of Hull University UK

Project for the design, supply, assembly, testing, installation and commissioning of a pair of bespoke Research Hot Cells for the University of Hull. The design is based on the standard Aquila Hot Cells with additional features and innovation to meet client requirements. The cells comprise, stainless steel containment with sealed access door and 75mm of lead shielding with hinged front access doors. The cells were designed to be installed in their assembled state to reduce installation time on site.

- **Material preparation and test equipment and instruments**

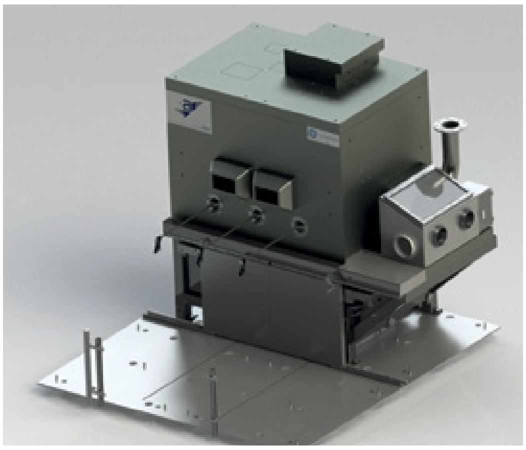
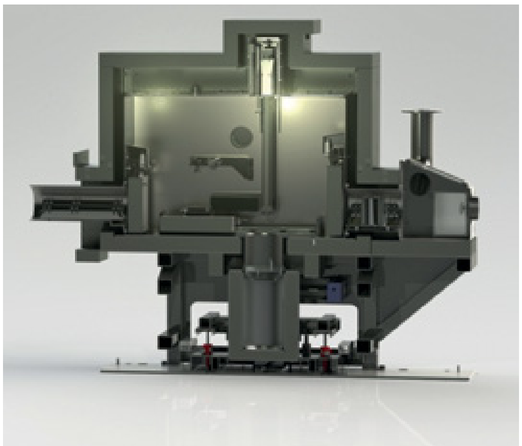
Used for post irradiation examination for example). This equipment may include, Electrical Discharge Machines (EDM), Electron Beam Welding machines, Scanning Electron Microscopes, Impact testers and Environmental chambers.





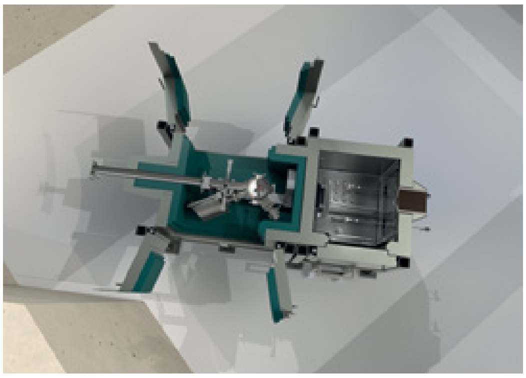
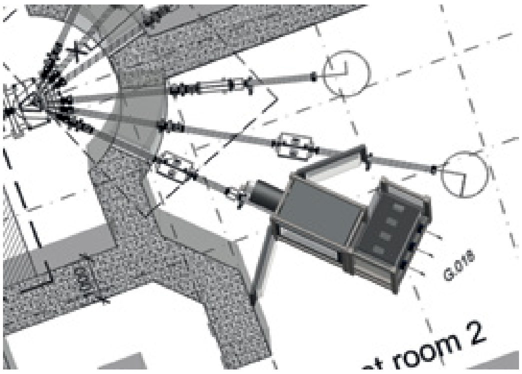
To assess the suitability of a concrete shielding cell and 3 Hot Cells within an existing Material Testing Facility, Aquila produced substantiated justification for not reinforcing/modifying the existing cells-scheme designs for an alternative to the concrete cell and the one Import Hot Cell. Aquila fully statically seismically qualified both designs and produced a decommissioning scenario for the existing 2 cells and a budget program and price for the replacement of those 2 cells.

- **Waste sorting, compaction, pyrophoric processes, washing (used for sorting and size reduction and decontamination)**

Aquila has supplied two shielded facilities with a single design, our scope included waste size reduction machinery and operational consumables. The plant is a 100mm lead shielded containment, operated via tong manipulators, with semi-automated devices to load/unload and dock shielded flasks and remove/replace storage drum lids. Connected to the main shielded containment via a shielded transfer tube, is an unshielded glovebox allowing LLW to trash out. The glovebox features a buffer area providing a route in for consumable items. SIL rates facility allows the waste to be measured, the ILW waste transferred into stainless steel drums for longer term storage and LLW to be transferred.

- **Sources and Beam Lines**

Aquila prepared a user requirement specification for a pelletron beam line Hot Cell. The Hot Cell shield design scheme derived was from an initial process and shielding requirement review. The final design was used as a basis of design from which the operational and equipment details could be developed.

As designers of Hot Cell Systems, we need to know the process so that we can design the most appropriate and safe system that will meet all of our client's criteria.

Two principal areas for integration of process into the Hot Cell, are shielding and containment. Taking radiological shielding first, we need to consider the following operational requirements:

- Remote Operation: MSMs, Tongs, Robotics
- Viewing: Windows, Cameras
- Control Strategy: Manual, Distributed Control-Sil rating
- Maintenance: Posting port, Shielded access panels
- Services: For gases, liquid, power, EC&I

D. Shielding

Take just one heading from the Aquila Influence diagram - Shielding:

Once we know the radiological specification for the product inside the Hot Cell and the criteria for the operational surface dose, we can prepare shielding calculations, or in many cases, our clients will provide us with the lead equivalent thickness.

We have a number of options for providing the shielding:

- Concrete
- Steel
- Lead

Of course, there may be additional shielding requirements depending on the mix of products inside the cell, so we could also have high density polyethylene and local shielding for instruments for example, like Tungsten, Cadmium or depleted Uranium.

Cost is always at the forefront of any project and the choice of shielding has a big impact on the outturn cost. If we normalise shielding cost back to concrete we can see that the price to design and install varies significantly between the materials above. If we compare just the cost of the shielding (without considering floor costs):

TABLE 1- Cost Comparison Shielding Material (without floor costs) :

Material	Thickness mm	Raw costs
Concrete	1,350	1.00
Steel	480	6.10
Lead	300	27.9

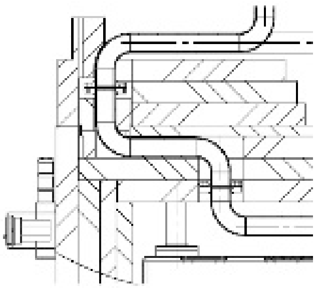
However, building floors costs money too, and the lower the density of the shielding material the higher the use of floor space. Now in existing buildings this may not be accounted for but for new facilities this may be a serious consideration. If we take floor space into account the normalised table looks like this:

TABLE 2- Cost Comparison Shielding Material (with floor cost assuming a cell 3m high and floor costs of €1880/m²):

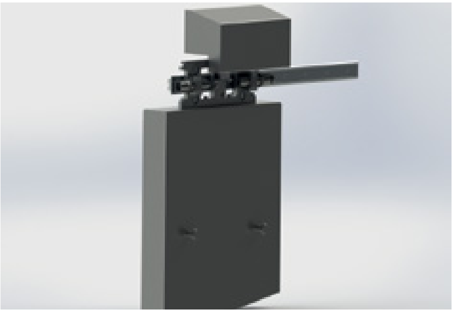
Material	Thickness mm	Raw costs
Concrete	1,350	1.00
Steel	480	1.65
Lead	300	6.20

So in summary, the difference in price for the shielding alone, for a suite of Hot Cells like the material test cells shown below, can amount to €2.5m or £2.1m for 500 tonnes of shielding.

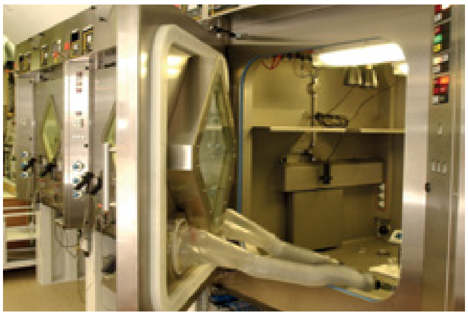
***Special Cautionary Note:**
It must be remembered that you cannot just use the raw material cost for budgeting a Hot Cell facility. The raw material must be engineered and manufactured into a Hot Cell which will involve a number of discrete manufacturing processes.



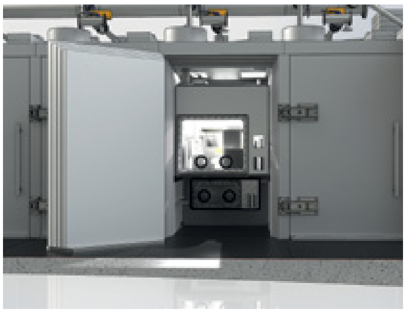
Whatever strategy we choose for shielding, the engineering must accommodate the functionality of the system, for example, penetrations for services employing the labyrinth principal, including the door functionality - sliding, hinged or hinged on air castor.



Sliding shield doors



Hinged shield doors



Hinged with air castors

Before we finish on shielding, we must also highlight trends in some areas for example, the environmental impact of using lead and not steel. Some sites have a resistance to using lead because of toxicity and other organisations see the benefit in the use of lead on the basis of sustainability. In other words, during decommissioning the lead can be totally recycled into the supply chain.

So, in summary, I am saying that the type of equipment located inside the Cells, the philosophy of operation and facility, will determine the most appropriate shielding solution.

Now, if we just had to provide shielding that would be too easy, so let’s assume we need to contain the process within a specific atmosphere.

E. Containment, Isolation and Gloveboxes

Most shielded facilities in my experience, are integrated with a stainless steel containment system or as a minimum, a stainless steel liner.

In most cases, the containment is maintained at a negative pressure for the protection of the operators. In certain processes the atmosphere inside the containment may need to operate under special environmental conditions:

- Inert atmosphere - Nitrogen or Argon for example
- Low Relative Humidity
- Stable temperature
- Localised laminar flow

Again, a clear statement of intent or a functional Requirement Specification (FRS) should be prepared and used as the Basis of Design (BoD). After the prime process and operational requirements have been identified, an assessment will define the most appropriate form of containment. In undertaking this work the containment specification will develop which addresses the applicable European and National safety codes and regulations.

In developing the specification, we must address issues like:

- Requirement to control exposure of hazardous material - breach flow conditions.
- Human factors assessment - combined with radiological shielding.
- Downstream maintenance activities
- Containment layout - which is a compromise between functionality, access, maintainability, exposure rate and other process activities. Together with the biological shielding no item can be treated in isolation.
- Routine housekeeping and maintenance including the criteria for decontamination of internal and external surfaces.

F. Classification of Containments

Containment philosophy varies between the nuclear and nuclear medicines industry and can be influenced by various factors:

- The results of a safety assessment and conclusions
- Whether the containment is primary or secondary containment
- Whether the box is free standing or part of a suite

Integrity Class I containments are described as primary containment with a leak rate allowance of 0.05% volume per hour at 10mbar.

Integrity Class II containments are described as secondary containments where the possibility of it becoming a primary containment is considered unlikely following the safety assessment. The allowable leak rate is 0.5% volume per hour at 10mbar.

In defining the required integrity, it is necessary to assess and specify many aspects such as:

- Levels of cover gas contamination within the glove box
- Cover gas rate of change
- Cover gas inflow velocities
- Operational pressure
- Reliability of emergency extract arrangements
- Ability of the system to accommodate fluctuations within the containment pressure
- Efficiency of Inlet and Extract filters

G. Containment assembly, Leak Testing and Flow

Great care and attention should be taken when assembling Containment systems as each feature and seal detail can contribute small leakage which when aggregated, can build up to gross leakage which cannot be validated to the required standard.

Flat seals have been replaced with engineered seals which ensure the highest level of leak tightness.

Air flow patterns are designed into the containment arrangement. These patterns reflect the process and are determined by the operation and failure mode identified during the risk assessment. The air flow can be calculated, modelled using CFD and ultimately verified by smoke trails.

Leak integrity test methods employed can vary from application to application and will be specified to be best practice. Many clients have a preferred methodology that must be followed. Best practice methods include the:

- Pressure rise method
- Parjo method

H. Conclusions

This paper provides an insight into the requirements for Hot Cell design based on over 25 years in the nuclear and nuclear medicines industry. It is important to come back to the mind-set that “Process is King” and project success is entirely dependent upon the use of appropriate specifications, standards and good robust design.

No element in the design, specification, manufacture, assembly and testing can be taken in isolation, the best solutions are fully integrated and considered. In our experience, this requires an iterative open approach with full project stakeholder buy in.

Aquila Nuclear Engineering Ltd

Aquila House,
Hazeley Enterprise Park,
Hazeley Road,
Twyford,
Hampshire,
England,
SO21 1QA
United Kingdom

UK: +44 (0) 1962 717 000
France: +33 (6) 67 99 83 02
E: info@aquilaeurope.eu

www.aquilaeurope.eu