The Design and Manufacture of Equipment for the Automated Sampling of Process Streams for the Hanford Waste Treatment Project-10267

Nicholas S Doyle

ABSTRACT

The Hanford Waste Treatment Plant (WTP) Autosampling System is based on a previous autosampling system at THORP Sellafield in the UK. The system is designed to automatically collect process samples and transfer them to an analytical facility. To satisfy the slurry handling requirements of WTP the autosampler design has had to evolve significantly.

INTRODUCTION

The Autosampling system (ASX) will be distributed across four building (Fig.1) at the Waste Treatment Plant (WTP) on the Hanford site in Washington State. The WTP is designed to vitrify legacy waste. The autosampling system supports this activity by collecting samples and transferring them to a remote analytical facility. In order for it to be able to fulfill this role the Autosampling system faced a number of new and challenging design requirements. Due to the complex nature of the Hanford waste some of these requirements directly conflicted with each other. Satisfying them and achieving a successful design required careful balancing of these engineering issues.

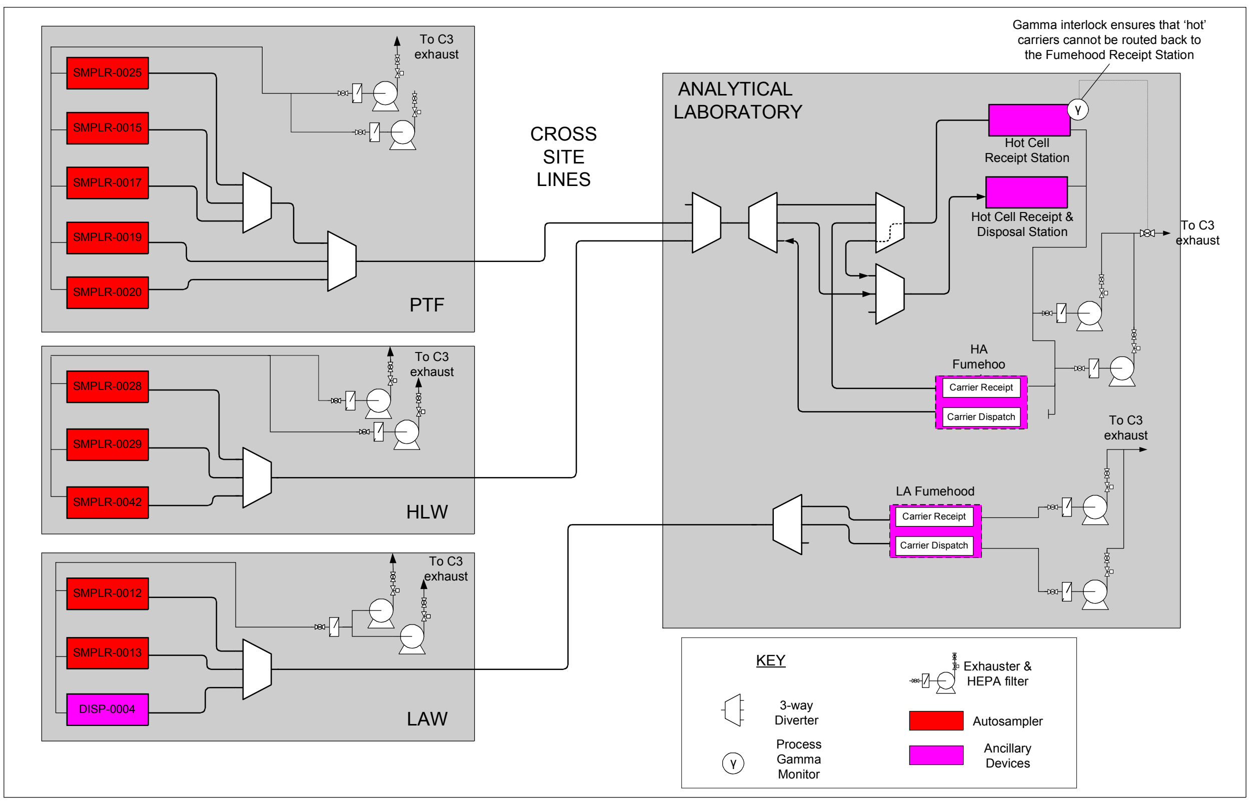

Fig.1. Schematic of the WTP ASX Autosampling System

Note: the Carrier Posting Station (DISP-0004) allows manually collected samples to be loaded into the carrier and dispatched to the lab.

There are four distinct types of containment devices in the autosampling system; the first of these are the autosamplers themselves, which are large gloveboxes containing sampling equipment. The autosamplers are wet boxes, as they potentially could be subject to spills and are equipped with wash rings, level detectors and drains.

The next type of containment device is the Hot Cell Receipt Station (HCRS). This is a smaller enclosure and is dry; it removes sample bottles from the sample carrier and drops them down a drop tube into the Hot Cell below. There is also the Hot Cell Receipt and Disposal Station (HCR&DS). This is not a containment device in itself, but rather a shielded valve located on the perimeter of the Hot Cell.

Finally there is the Fumehood Receipt Stations which facilitate dispatch and recovery of samples. All of these devices are connected via a Pneumatic Transfer System which moves samples from one location to another.

PREVIOUS AUTOSAMPLING CONFIGURATIONS

The current ASX configuration has evolved significantly from previous designs. There are three existing autosampling systems at Sellafield in the UK. The largest of these is on THORP. This system consists of 42 autosamplers and a number of other simpler glovebox samplers and miscellaneous sampling devices. The pneumatic transfer system (PTS) was segregated into 4 separate lines, High Active (HA), Medium Active (MA), Low Active (LA) and Plutonium Active (PA). These systems take samples from the sampling devices (typically an autosampler) and route them to an analytical laboratory or hot cell. The UK PTS has route distances of up to 1.5 kilometers.

Features of the UK autosampling system (Fig.2) are small simple standardized sampling units, narrow sample needles (1 mm bore), PVC flight tubes, limited sample volumes (15ml), heavy sample carriers, and an extensive marshalling room to support carrier dispatch and receipt. Shielding is provided only on the MA and HA autosamplers. Overall the system has worked extremely well, although it is only required to sample relatively straight forward unpressurized process streams. It successfully achieved these goals and provided reasonably good accuracy. However a number of WTP requirements (see below) could not be satisfied with the existing design.

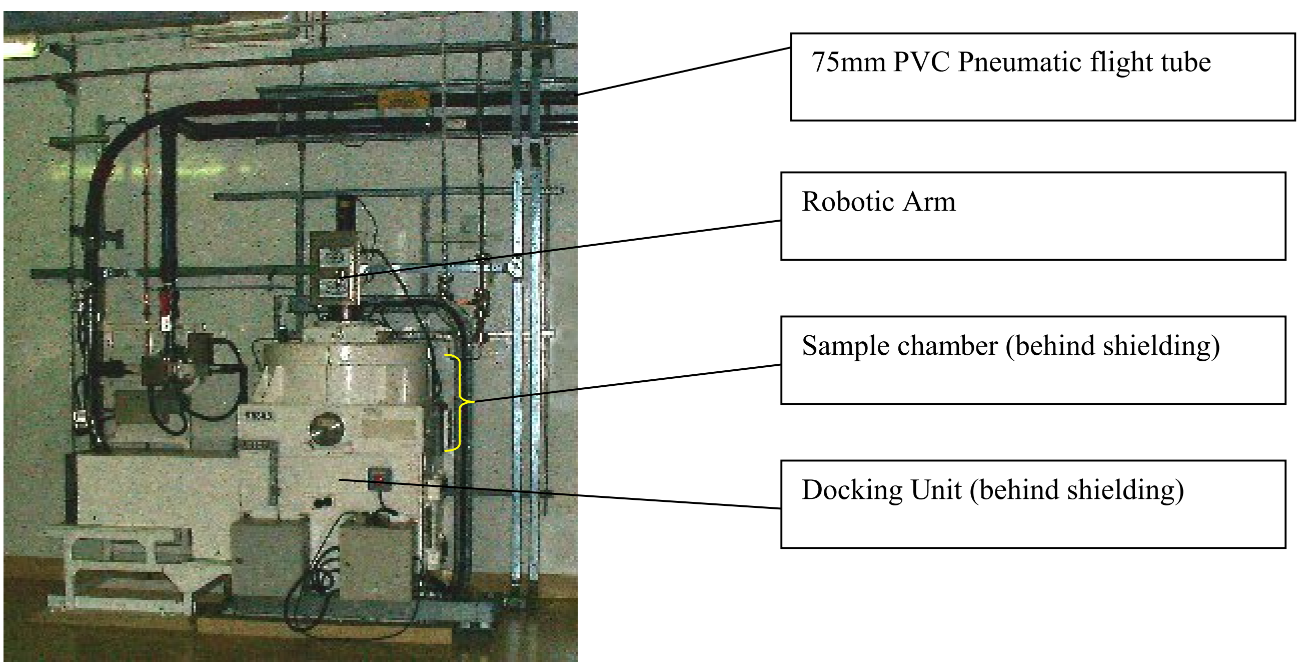

Fig.2. THORP Shielded MA Autosampler

The UK autosampler configuration is a compact machine with a nominal footprint of 1.2m (~4') ×2m (~6.5') wide ×2.4m (~8') high and weighed up to 11,000 kg (~25,000lb). The unit has single layer of external lead shielding up to 150mm (~6") thick. Process sample lines are small typically 20mm (¾" Sch 40). A robotic arm is mounted on the top of the sample chamber and the docking unit is located along side the sample needles in the chamber base. The mechanics of the robotic arm and docking unit have been engineered to allow manual recovery of a sample at any point in the sample cycle. It should be noted that apart from the robotic arm and docking unit there are no moving parts behind shielding.

When initially reviewing the UK design it was determined that the Controlled Arrival Facilities, robotic arm, docking unit and docking port could be used with limited modification.

ASX DESIGN REQUIREMENTS

The following are some of the key requirements that had to be satisfied in the ASX design.

Weight and volume constraint

The permitted envelope for ASX autosamplers was typically 2.4m (8') × 2.4m (8') with 2.4-3m (8-10') of headroom. The maximum weight was 22,730 kg (50,000lb).

Source Term

Source terms were specified for three principal isotopes for each process line. The bounding values were Cs-137 (4.88E+8 Bq/cm^3), Co-60 (1.92E+6 Bq/ cm^3) and Eu-154 (9.67E+6 Bq/ cm^3). Permitted external dose rates varied from 2.5µSv/hr at 0.3048m (0.25 mR/hr at 12") to 25µSv/hr at 0.3048m (2.5 mR/hr at 12").

Sampling Requirements

Accuracy

The sampler had to achieve best possible accuracy. There are a number of elements that contribute to the obtaining good accuracy; these include homogeneity in the tank, maintaining the homogeneity in the sample loop (which may necessitate turbulent flow), extracting a representative sample at the sample point and good laboratory analytical techniques.

Note: Laboratory analysis of the sample is outside the scope of this paper.

Volume

The required sample volume is to be up to 15 mL for High Active (HA) samples and 35mL for Low Active Waste (LAW) samples. The volume size to be adjustable in 5 ml increments.

Flushing

Sampling the viscous slurries required that needles be flushed clean after every sample.

Sample Points

The autosampler configuration had to be capable of accommodating up to six sample points.

Process conditions

Sample Line Size & Pressure

The sample process lines were typically either 25.4mm (1") or 50.8mm (2") in diameter. The design had to be able to accommodate line pressures of up to 16.2 bar (239 psig) and flow rates of up to 662 L/m (175 gpm). High velocities were often required to ensure the process stream remained homogenous. For the autosampler this is a significant difference from the UK configuration where all the sample lines were maintained at a negative depression.

Non-Newtonian liquids

Sample streams could be highly non-Newtonian, 30 Pa yield stress and 41mPa-sec shear rate.

Slurries
Moving slurries through narrow lines is intrinsically difficult. The slurries on WTP can contain up to 40% solids (by weight). Particle sizes can be up to 249 microns (176 microns at 99.5%).

Expected Equipment Life
Along with the rest of WTP, the autosampling equipment had to be designed to meet an expected life span of 40 years. Any components that could not meet this requirement had to be fully maintainable with minimal associated radiation dose.

DESIGN CHALLENGES & SOLUTIONS

Equipment configuration

The ASX Autosamplers are derived from, and shares many of the characteristics of, the UK autosampling system in that they consist of a confinement barrier interfacing with robotic machinery for collecting a sample. However the requirement to accommodate an Isolok sampler with downward pointing needles and flush capability, as well as larger process lines into the autosampler design lead to a significant divergence in equipment layout. In addition for one of the autosamplers (ASX-19) the provision for sampling an additional process line was required. This was achieved by installing a 3-way process valve such that one sample needle serviced two process lines (Fig. 5).

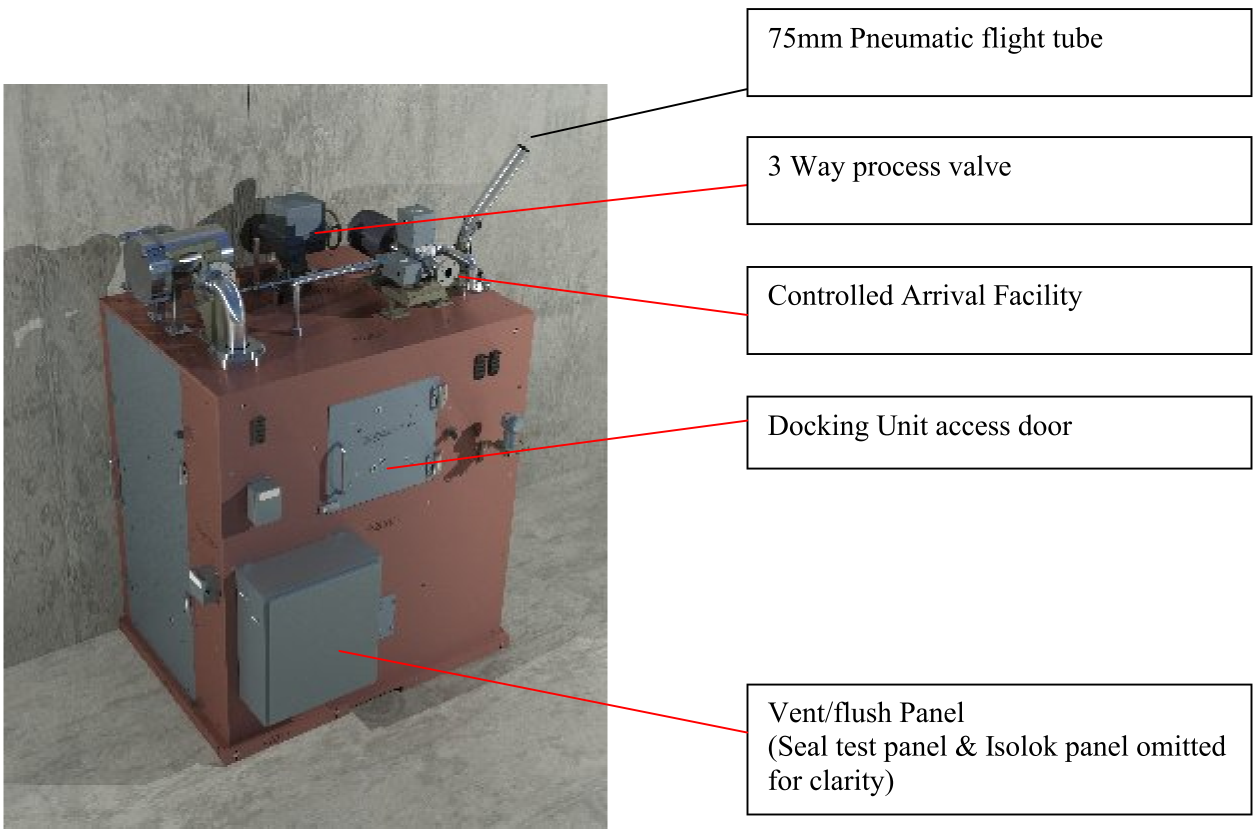

Fig.3. Autosampler Assembly (ASX-19)

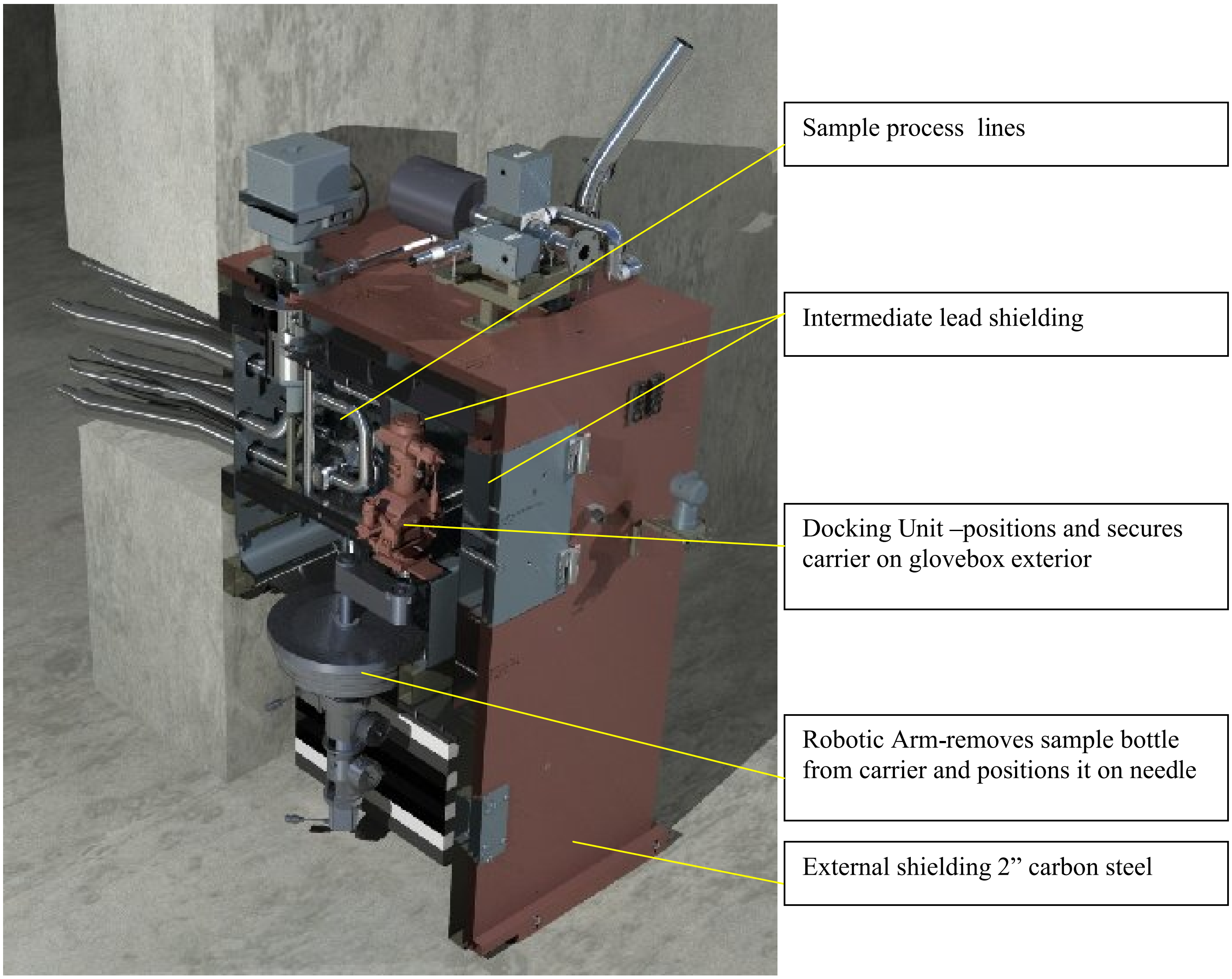

Fig.4. Section of Autosampler Assembly (ASX-19)

Equipment Envelope

Accommodating six sample points and their associated Isolok samplers into a compact glovebox proved challenging. Ideally in a well laid out glovebox the operator should be able to access all surfaces (for maintenance, swab checks and decontamination). However, the need to accommodate six Isolok samplers and their associated shielding required a large glovebox. The Isoloks not only required a larger glovebox, they also required maintenance, and this further increased the size of the glovebox. The conflicting requirements for a small compact box, adequate maintenance space and provision of local shielding were carefully balanced as the design evolved. The final glovebox envelope was 0.9m (3’) deep × 1.7m (5 ½’) wide. All maintainable equipment was located so as to be within reach of the operator.

Shielding

Due to the significant source activity and the large sample line sizes, it was established, via Monte Carlo N-Particle Transport Code (MCNP) modeling, that up to 200mm (8”) of steel shielding (or an equivalent combination of steel and lead) was required for the largest source terms. The simplest approach (and the one adopted for the UK autosamplers) is to have a single external layer. However given the size of the glovebox and its supporting frame, a single external layer of shielding would have been excessively heavy. In addition it was necessary to minimize the dose to the operator during maintenance (when the access shield doors would be open) as well as to the electronic equipment inside the glovebox.

These requirements were satisfied by the use of a layer of shielding located inside the glovebox (local shielding) and additional layer of shielding located between the exterior of the glovebox and the frame (intermediate shielding). For the external shielding a 5cm (2") layer of carbon steel was used. For the local shielding lead filled hollow forms were used. For the intermediate shielding either steel plate or lead was used depending on the shielding requirements.

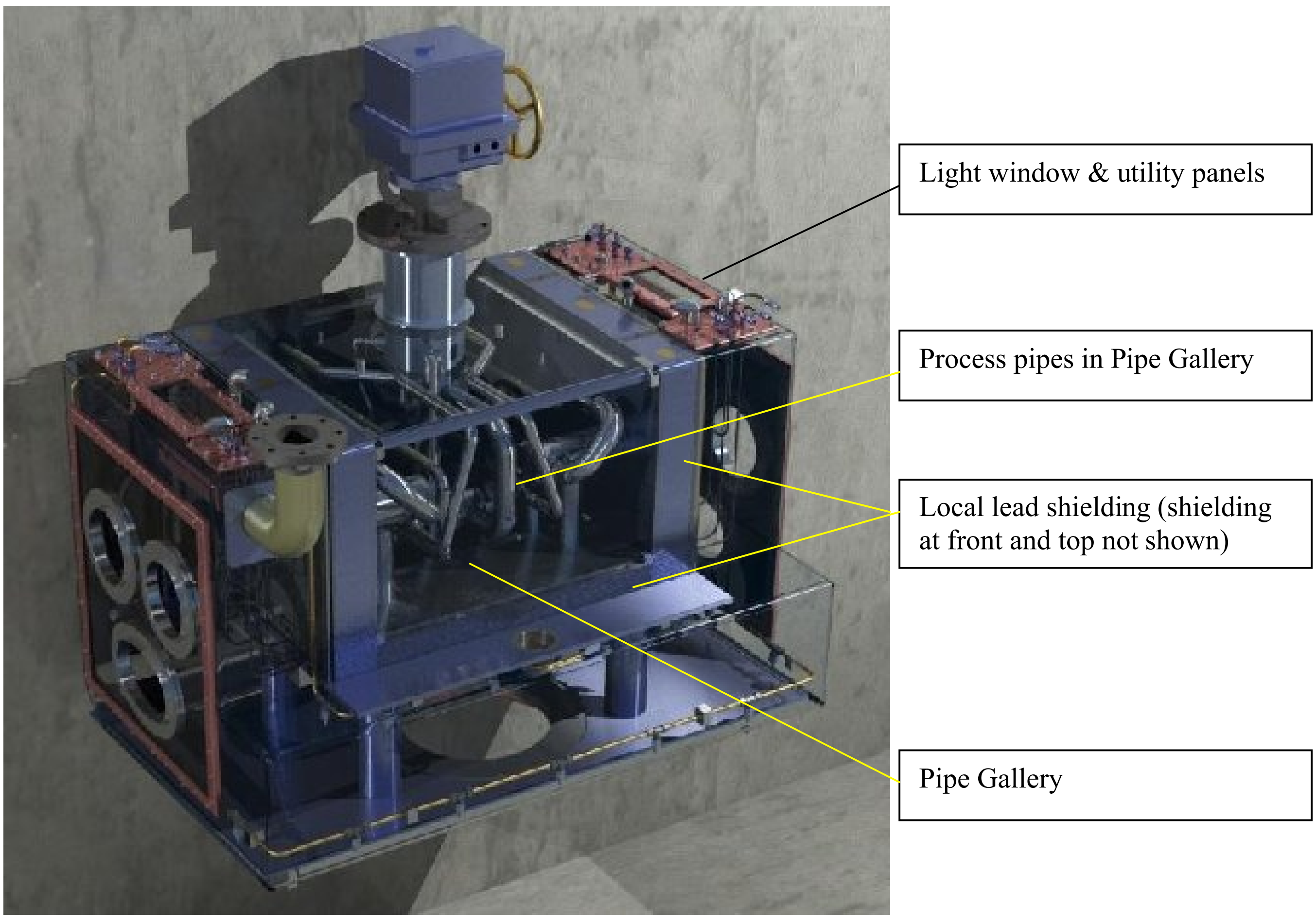

Fig. 5. Autosampler Glovebox (Frame, external and intermediate shielding omitted for clarity)

The pipe gallery in the center of the glovebox is segregated from the rest of the glovebox by thick lead shielding. In addition the pipe gallery shares the black cell air space and is segregated from the glovebox. This isolated the exterior of the process pipe work from the most likely sources of contamination. As a contingency an inspection port was provided to allow for inspection/decontamination of the pipe gallery. To accommodate the long radius pipe bends the shielding at the front of the pipe gallery had to be thinner than the sides, this was compensated by heavy lead intermediate shielding and the use of tungsten for the most 'source term' challenged machine (ASX-020).

Glovebox Cleanliness

There are two aspects to glovebox design, firstly ensuring that activity cannot migrate out of the glovebox, and secondly, ensuring that contamination inside the glovebox is minimized. This latter aspect was addressed at a very early stage in the design process when it was determined that all process liquids would remain enclosed behind a physical barrier. The only exception to this is the flush drain line which discharges deep into the glovebox drain below the base of the glovebox.

Isolok Sampler

Due to the requirement for high accuracy and the pressures encountered in the process sample lines a mechanical sampler was required. A number of samplers were considered and the Isolok sampler was finally selected. These samplers are widely used in non-nuclear applications and have a good track record for obtaining representative samples. They also provide a mechanical seal between the process stream and the glovebox environment.

The integration of the Isolok samplers into the autosampler design was probably the biggest challenge encountered in the ASX design. The manufacturer of the Isolok (Sentry Equipment) had advised that their equipment had only been developed to support downward pointing needles (which was the reverse orientation to the standard UK configuration). Meeting this requirement lead to a substantial reconfiguration of the autosampler. In addition the Isolok sampler is a complex piece of equipment with multiple o-rings and moving components. These components will need periodic maintenance. It was therefore necessary to configure the autosampler so that the maintenance operator would be shielded from the source term in the process lines. The autosampler therefore needed to perform two different functions; act as a glovebox, which allows for operator access but is typically used for relatively low radiation sources, and also to act as a heavily shielded bulge.

In order to accommodate the downward orientation of the sample needles the robotic arm was inverted and located below the autosampler. To address the high activity, the process pipes were enclosed in a shielded pipe gallery. The Isolok's casing was modified so that all the utilities (compressed air and flush water) were routed through the end of the sampler. With the protrusions removed from the Isolok exterior it was then possible to mount them in a cylindrical sleeve that penetrates the lead and steel shielding of the pipe gallery.

Due to the size of the Isoloks the spacing between the sample needles increased. This was accommodated by increasing the radius of the robotic arms carriage. This did however result in an unavoidable increase in the glovebox size.

Process Conditions

The most challenging process streams are the High Bound HLW and LAW melter feed. These process streams will have glass formers blended in and are non-Newtonian slurries (Fig. 6).

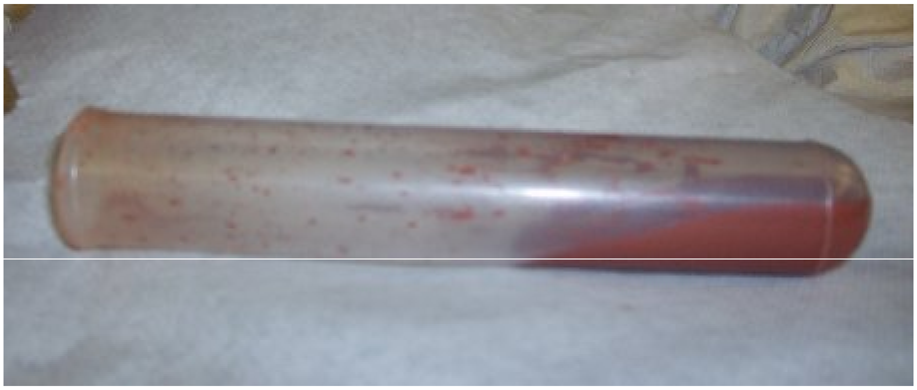

Fig.6. HLW High Bound Simulant: Non-Newtonian characteristic are clearly visible-the liquid is unable to flow out of the open test tube.

Because the Isolok uses a double piston to extrude the sample into the sample bottle, the non-Newtonian properties had little impact on the Autosampler design. The slurry properties however, were much more problematic and required significant investigation and development work. This involved modifying the Isolok sampler and receiver nozzles and bends (both areas that are prone to slurry blockage). Also the sample line diameters were increased and the sample lines arranged such that the narrowest sections occurred in components that could be readily (or automatically) replaced. These design features were developed and tested on a prototypic test rig at the Vitreous State Lab at Catholic University in Washington D.C. The slurry simulant had particle sizes up to 425 microns (350 microns at 99.5%) therefore bounding the plant process requirements. During these development trials when blockages occurred back flushing was found to be extremely effective and was therefore added to the most susceptible sample points (HA Melter feed samples).

Flushing Requirements

The ability to flush was constrained by the self imposed requirement that all liquid streams be enclosed. A route needed to be designed to route the flush stream from the needle down to the drain. The mechanism needed to be simple and require minimal maintenance. It was finally determined that the sample cap itself offered the best arrangement for flushing the needle. In order to do this the sample cap (which had previously been used in the UK) was fitted with a second septum. This created a small atrium in the lid. The atrium was used to divert the flow from the inner needle into an outer co-axial needle from where it is routed down the glovebox drain. The lid septum's are a self sealing configuration that had previously been developed to contain high alpha samples (Plutonium nitrate). Valving was provided (external to the glovebox) to allow water or air to be directed through the needle. A small development program established the correct flush pressure to ensure there was an adequate flow of water without generating excessive pressure in the flush cavity (which could force flush water out of the sample bottle).
Note: water is used to flush the needle & Isolok and then air is used to dry off the residual water droplets.

In addition to providing a flush capability the modified sample cap allowed for a number of automatic checks to confirm presence (and correct positioning) of bottle, cap, and needle. This is important as the most likely cause of contamination in the glovebox is from inadvertent Isolok operation. Automatic needle blockage checks are also performed after the sample is taken to ensure the flush has been successful.

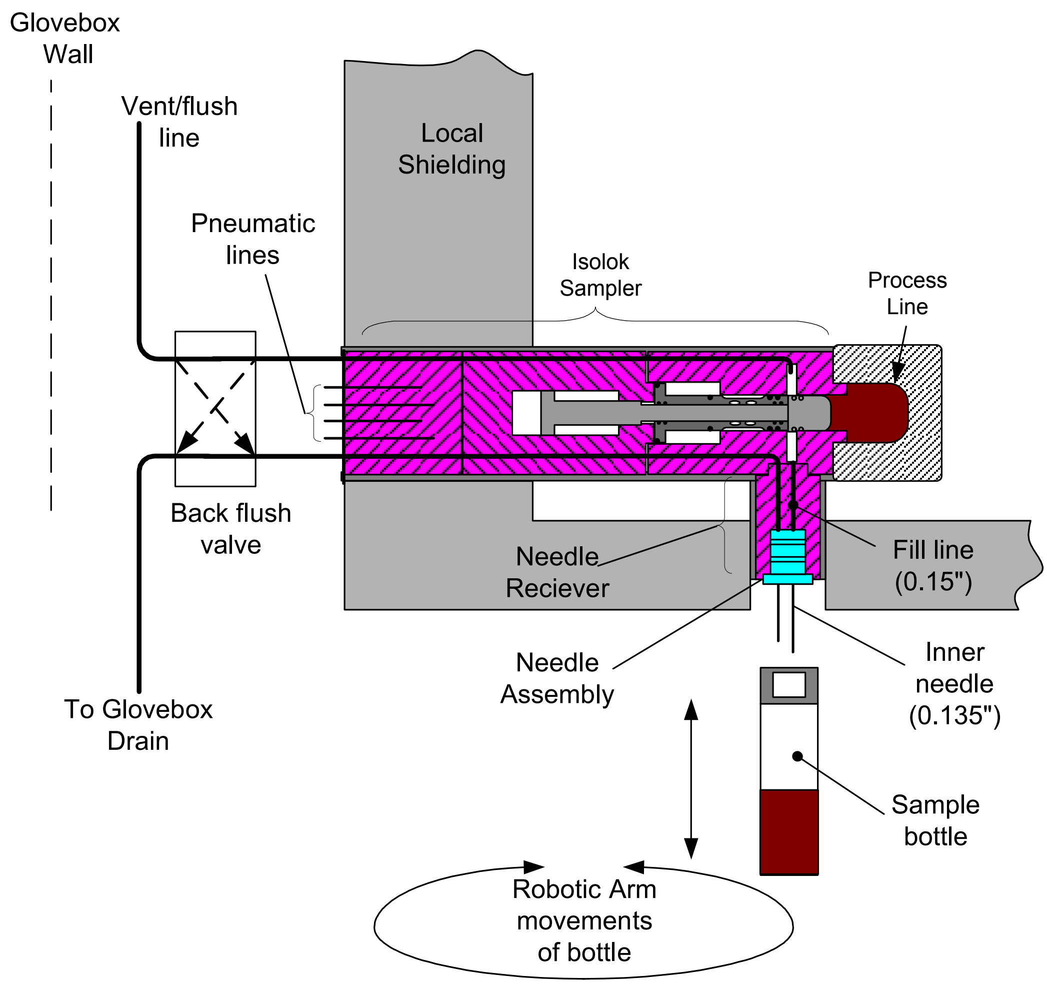

Fig.7. Schematic section through Isolok sampler –the Isolok and needle receiver (shown in magenta) may be manually replaced. The needle assembly (shown in cyan) may be replaced automatically

Sample Needle Size and Geometry.

This was another area where two engineering requirements were in direct conflict. For adequate sealing of the sample cap the needle diameter needed to be kept to a minimum. However slurry handling requirements are that the sample line size be kept above a minimum threshold to avoid the risk of blockage. To overcome the blockage issue the sample line ID was increased to 3.8mm (0.15”). The needle ID was set at 3.5mm (0.135”). This was intentionally smaller than the line size to make the needle (which can be replaced automatically) the ‘weak link’ with respect to blockages (Fig.7). This resolved the blockage issue but introduced two problems. The sample caps were now being penetrated by a very large double needle which had an outside diameter of 5mm (0.203”). This was significantly larger than the original design and could have compromised its sealing ability. To overcome this, a second lower septum was added to the sample bottle cap. This improved the sealing of the cap and ensured that flush water would not leak into the sample (thereby compromising its accuracy). In addition the precision with which the bottle had to be aligned was becoming untenable. In order for the sample cap to seal the needle has to penetrate in a central region of the septum. As the needle got larger the permissible alignment tolerances became extremely tight. This problem was finally resolved by making adjustments to the sample bottle, robotic arm and needle receiver to allow for a self alignment feature to be accommodated into the design.

Process Line Sizes

In order for the process stream to remain homogenous the flow needed to be turbulent. Achieving this without excessive pressure drops required large line sizes. The requirement to accommodate 5cm (2") process lines had two impacts; it increased the source term inside the autosampler and the required envelope. The latter was significant because the process pipes required long radius bends (to minimize the potential for erosion). As a result the local shielding at the front of the pipe gallery had to be made thinner than the side pieces (Fig.5).

Pneumatic Transfer System

Typically the flight tubes for these systems are made from PVC or steel tube. PVC was considered undesirable due to its potential fire hazard. Also steel tube has relatively thin walls increasing the potential of damage to the flight tubes which could result in a stopped carrier. It was therefore determined that the flight tube should be fabricated from steel pipe. As there was limited previous operational experience with this material a small PTS test facility was set up to assess the performance of the steel pipe. It rapidly became apparent that the sample carrier felt wear bands would need to be modified as the existing felt bands were wearing out at a rapid rate. The felt was replaced by Ultra High Molecular Weight Polyethylene (UHMWPE) which proved to be much more resilient.

Sample bottle/carriers

The previous UK sample carrier design was limited to 15ml. There were three options to increase the sample volume, increase the carrier diameter, increase it's length or modifying the mounting arrangement for the bottle. The first two options would have had significant impact on other equipment e.g. the docking unit and its associated docking port. The carrier lid was therefore re-designed to make the lid closure and bottle retention mechanisms simpler and more compact. Rather than using the previous complex arrangement of spring loaded locking pins, garter springs were used. The space occupied by the lid and mounting mechanism which occupied half of the carrier volume was reduced by 50%. This meant the carrier could accommodate a larger sample bottle and had the added benefit of reducing the carrier weight.

ANCILLARY EQUIPMENT

Dispatch & Receipt Devices

In addition to the autosampler there are several other significant pieces of equipment on the autosampling system. The carrier with the sample bottle is routed to the Hot Cell Receipt Station (HCRS).

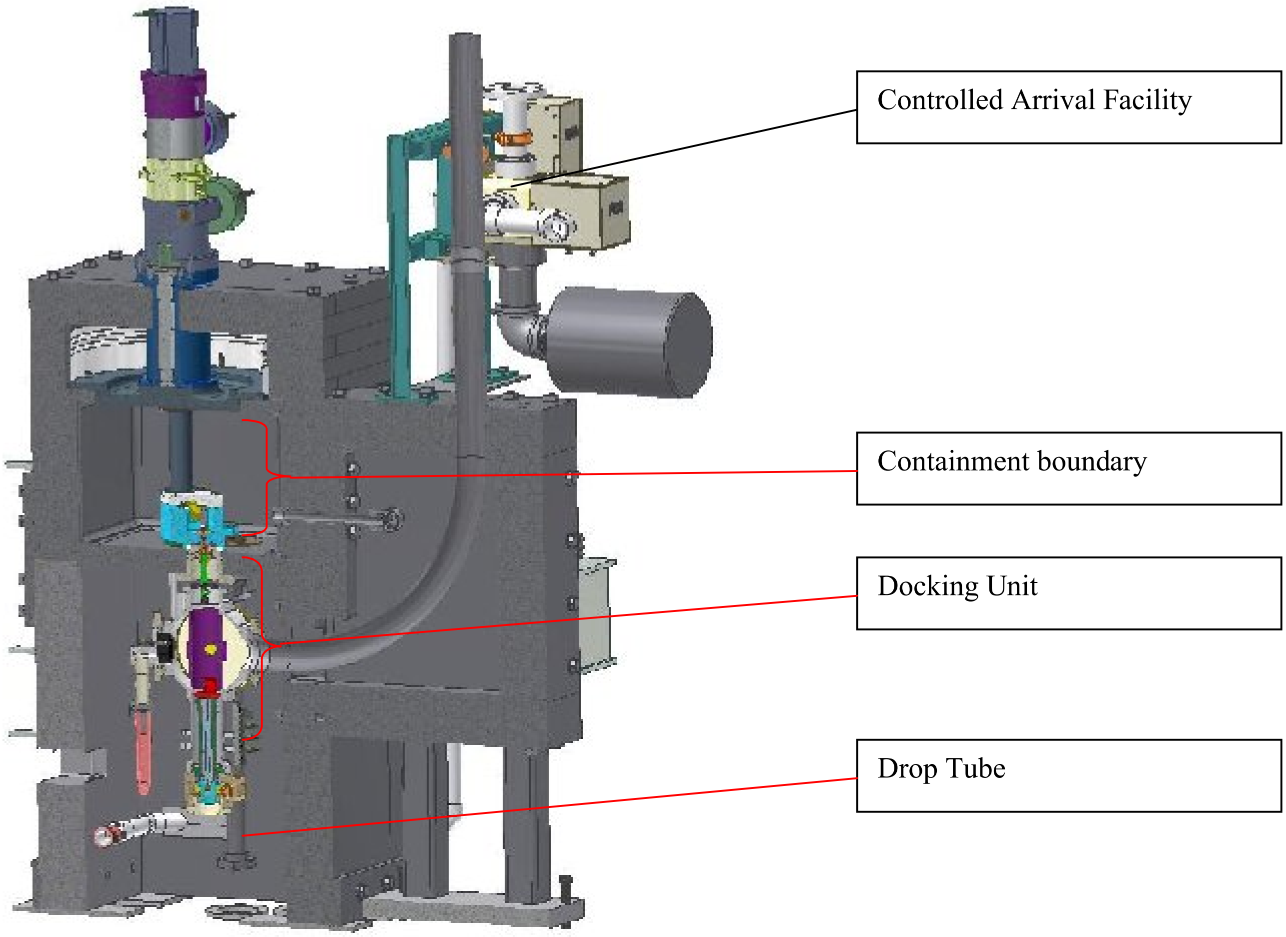

Fig.8. View of Hot Cell Receipt Station (HCRS)

The HCRS differs from the autosamplers in that its robotic arm is roof mounted and has a much shorter radius. The HCRS receives the HA sample carrier, rotates and seals it to the base of the chamber, splits the carrier and then drops the bottle into the Hot Cell below. To keep the equipments foot print to a minimum the frame was eliminated and the shielding was designed to be self supporting. This allowed the foot print to be reduced to 1.0m (39”) × 1.4m (55”) whereas previously in the UK these units had a foot print of 1.2m (~4’) ×2.1m (~6.8’ 10).

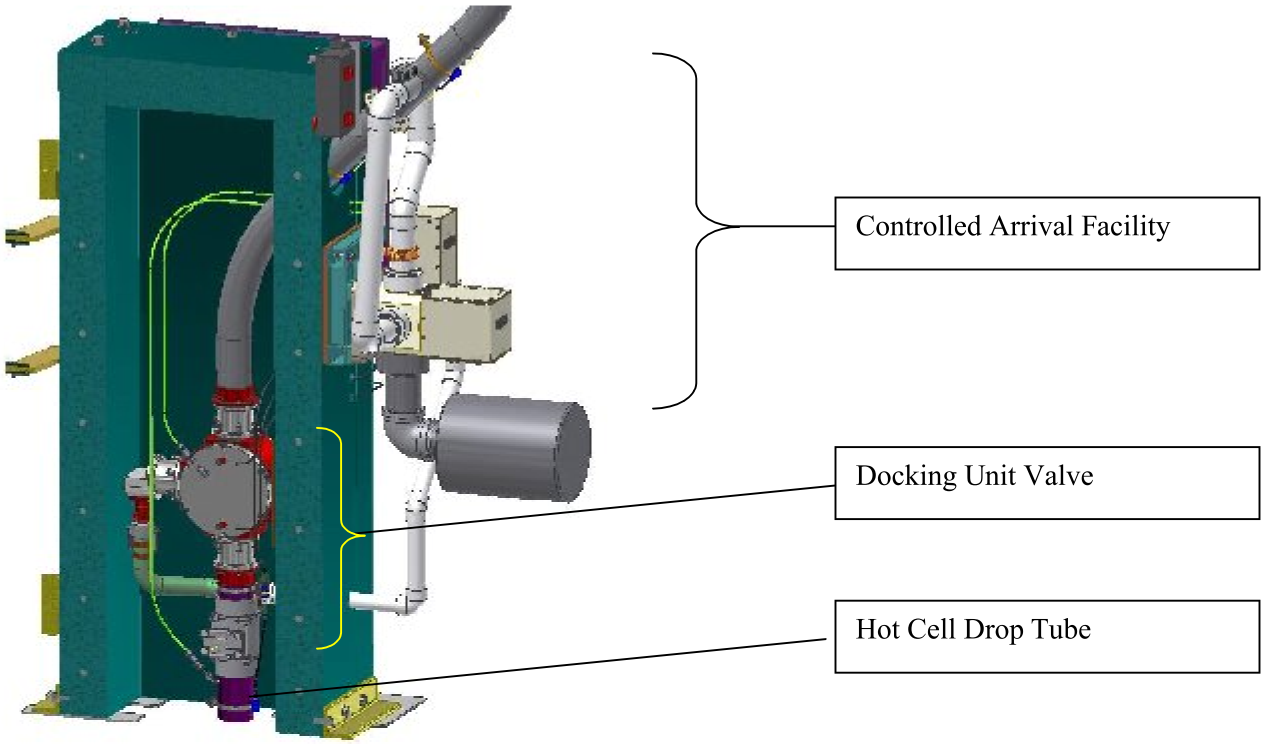

Fig.9. Section through the Hot Cell Receipt & Disposal Station (HCRDS)

The HCRDS is a much simpler device than the HCRS. It provides a disposal route for carriers that are too contaminated to return to the Fumehood Receipt Station. The carrier flies into a cup shaped container in the Valve Docking Unit. The cup rotates 180º and drops the complete sample carrier down a drop tube into the Hot Cell below. The carrier is then split using a Carrier De-lidder (Fig.10).

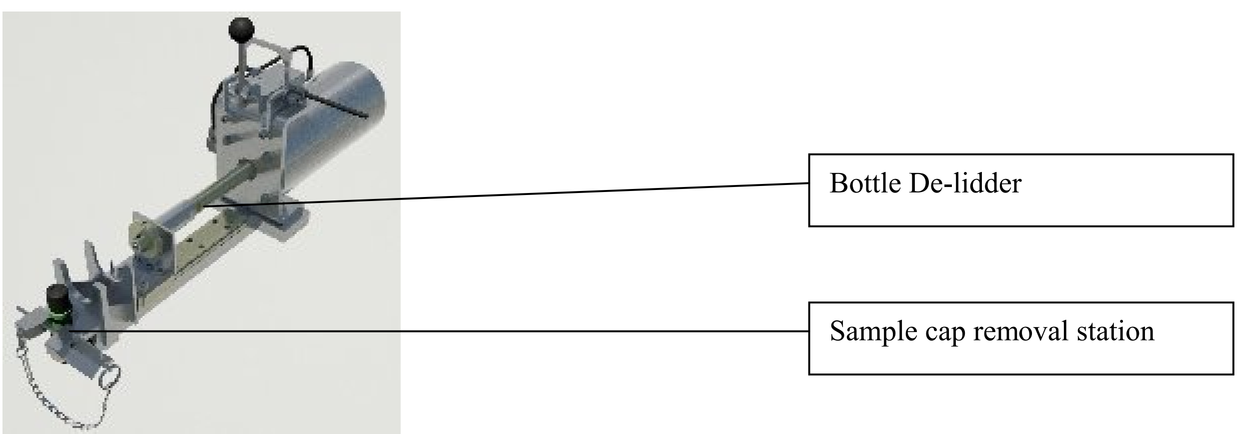

Fig.10. Carrier De-lidder

The carrier De-lidder is designed to be operated with Hot Cell MSM's allowing the operator to open the carriers, remove used needle assembly's and also to open the sample bottles.

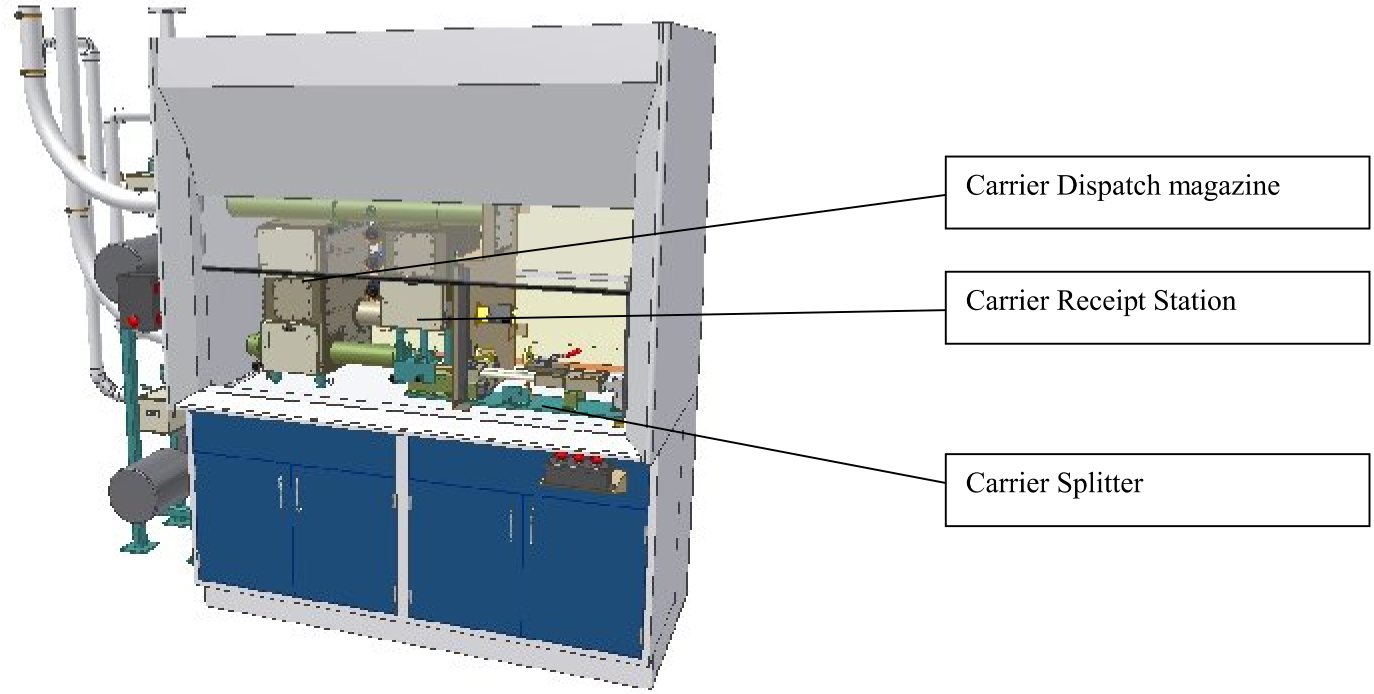

Fig.11. View of Fumehood Receipt Station (FHRS)

There are two Fumehood Receipt Stations (FHRS), one for LA samples and the other for HA samples. A gamma interlock prevents ‘hot’ carriers from being routed back to the FHRS. The FHRS has a carrier dispatch magazine which holds up to 20 carriers loaded with sample bottles, a Receipt station that can hold up to 20 sample carriers (containing samples for LA but empty for HA). In addition there is a carrier splitter for loading and emptying the carrier as well as bar code readers that record the bar code numbers on the bottle and carrier. This configuration is significantly more compact than the previous UK configuration combining the functions of three machines; a Carrier Buffer Store, an Automatic Bottle Dispatch Facility and a Dispatch and Receipt Glovebox.

Conclusion

As can be seen the Waste Treatment Plant imposed a number of unique and challenging sampling requirements. The autosampler design was successfully adapted to these requirements using a conservative design approach and the careful balancing of conflicting requirements.