Portable and Modular Cementation Systems for Stabilization of Nuclear Wastes – 11367

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ABSTRACT

Worldwide, cementation is the most prevalent technology used to stabilize nuclear wastes and it is often the reference technology against which other techniques are compared.

Traditionally large, expensive, fixed "monolithic" plants, often utilizing hot cells have been constructed for cementation of nuclear wastes, and where there is a large legacy waste inventory (Savannah River's Saltstone) or an ongoing process mission (Sellafield's Waste Encapsulation Plant) this may be appropriate.

Energy*Solutions* has developed a suite of portable and/or modular systems for use when a monolithic concept is neither necessary nor desirable, due to factors such as space, budget or schedule constraints or low waste volumes, etc. Such systems have been used by Energy*Solutions* for over 35 years, resulting in the stabilization of more than 13.2 million liters (3.5 million gallons) of radioactive waste in over 45 nuclear facilities.

Generally these cementation systems utilize as much or as little of the clients' infrastructure as is appropriate (utilities, cranes, filtration and ventilation, pumps, biological shielding, etc). Wastes typically processed include, evaporator bottoms, ion exchange resins and spent fuel pool sludges, but treatment of other wastes is common.

Waste containers include: Standard 2.3–5.7 m^3 (80-200 ft^3) steel solidification containers, High Integrity Containers (HIC), 200 liter (55 gallon) and 3m^3 drums and tailored specialty containers. A proven "lost paddle[1]" approach is generally used, where the container incorporates an internal paddle to ensure good blending of the waste, make-up water, additives and cement materials without radioactive contamination of other equipment.

The Energy*Solutions* systems currently fall into four product families: Mobile and Portable Solidification Units (MSU and PSU); MObile Sludge Solidification System (MOSS); Canyon and Modular Intermediate Level Waste Processing Plants (CILWPP and MILPP); and Glovebox Cementation Mixing Systems (GCMS). System selection is driven primarily by the characteristics of the waste being processed and the customer's preferred waste package geometry.

This paper will concentrate on the challenges posed by the radioactive properties of wastes on cementation design and the systems that have been developed to address these challenges. The paper will also describes the benefits of portable and modular cementation systems compared to monolithic alternatives, discussing advantages in cost and schedule; equipment reuse from facility to facility; throughput; decommissioning and secondary waste generated. The relative merits and applicability of each system type for different applications will be discussed highlighting where these systems have been previously applied. Lastly the paper will discuss where research and development has been performed to ensure achievement of product quality and other client requirements.

INTRODUCTION

Cementation is generally used as an immobilization technology for all but the most challenging waste forms and is usually selected for its known maturity, its relative simplicity and its low lifetime cost.

When selecting cementation as a technique for immobilizing wastes, the designer must first consider the chemical and radioactive properties of the waste, particularly in relation to the waste acceptance criteria for the ultimate waste repository. When examining the chemical properties of the waste, consideration of the water content and the pH is important and these properties are often adjusted by pretreatment processes such as neutralization when the pH is below seven, or dewatering where the water content is unnecessarily high and will lead to an excessive number of waste containers. In addition the order and timing of processes can affect product quality and careful study of types of cements or cement additives and post-solidification handling is important, particularly in applications where a monolithic cement package and/or a concrete with a minimum allowable hardness is required.

[1] The "lost paddle" design utilizes a sacrificial mixing paddle, which is internal to the drum and is left in place within the drum as the waste solidifies.

The radioactive properties of the waste also have a significant effect on the cementation system equipment design and in particular the amount of gamma and alpha activity in the waste affects the amount of shielding and confinement necessary to facilitate operation and maintenance, which in turn significantly impacts the geometry of the system.

Finally the client's cost, schedule and throughput targets are critical factors in the selection of the right system for that application.

SYSTEM SELECTION

A great many US nuclear facilities have a need to dispose of relatively large quantities of Low Level Waste (LLW). Often this waste emits low enough levels of gamma radiation that short term exposure to operators is acceptable. For these applications Energy*Solutions* would usually recommend use of a PSU/MSU solution.

For wastes that emit significantly greater gamma radiation, a shielded solution is required and this can be achieved by either building shielding around the grouting system, but retaining the bulk of the drives and control equipment outside the shielding (i.e. CILWPP); or by locating the whole grouting system in an room with walls that provide shielding during processing but allow access when the source term is removed (i.e. MOSS). Choosing which option is best for each application is often a complex subject requiring careful comparisons of the client requirements versus the cementation system characteristics.

Wastes that have a high content of alpha-emitting isotopes are a particularly difficult challenge and require high degrees of confinement to minimize operator contact with these harmful materials. Energy*Solutions* has pioneered the GCMS system for these applications by integrating a compact cementation system within a high integrity glovebox. Table I lists recent Energy*Solutions* cementation systems applications illustrating the wide versatility of cementation technology for stabilizing nuclear waste.

Table I. Recent Energy*Solutions* Cementation Applications with Waste Characteristics

Cementation System/Location	Alpha	Gamma	Drum Size	Waste Type	Repository
Hanford K-Basin (MOSS)	Medium	Medium	208 l (55 gal)	RH-TRU	WIPP
Idaho CPP-603 (PSU)	Low	Medium	$6m^3$ HIC	LAW	Clive, NTS
Hunterston (CILWPP), UK	Medium	Medium	$3m^3$	ILW	RWMD ILW
Sellafield B30 (MILWPP), UK	Medium	High	$3m^3$	ILW	RWMD ILW
Savannah River WSB (GCMS)	High	Low	208 l (55 gal)	CH-TRU/LAW	WIPP/NTS

Glossary of Terms
B30 – Building 30 at Sellafield, UK
Clive – Energy*Solutions'* low level waste repository in Utah
CH – TRU – Contact Handled Transuranic Waste
HIC – High Integrity Container
ILW – Intermediate Level Waste (UK Classification)
LAW – Low Active Waste
NTS – Nevada Test Site, NV
RH – TRU – Remote Handled Transuranic Waste
RWMD – Radioactive Waste Management Directorate (part of UK Nuclear Decommissioning Authority)
WIPP – Waste Isolation Pilot Plant, NM

PORTABLE AND MOBILE SOLIDIFICATION SYSTEMS (PSU/MSU)

Over the last 35 years, Energy*Solutions'* have used Mobile and Portable Solidification Units for on-site, in-container solidification of more than 13 million liters (460,000 cubic feet) of low-level radioactive at 45 nuclear facilities including BWRs, PWRs and other waste generating nuclear sites. These wastes have included:

- Evaporator bottoms
- Resin beads
- POWDEX™ resins
- Filter sludges
- Filter precoat backwash
- Resin regeneration wastes (sodium sulfate)
- Decontamination solutions
- Oil sludges and oil

MSUs and PSUs comprise of essentially the same equipment and the solidification function and basic operational design of both are identical. MSUs are typically supplied to the customer in shipping containers capable of being sited outside the nuclear facility and are designed for maximum flexibility to connect readily to the customer waste collection systems. PSUs were developed for use inside a utility radwaste building and are skid mounted for longer term use at the waste generating site.

Both systems feature a multifunction mixing and filling head which lowers onto waste containers to dewater; add cement and waste, drive the paddle; vent and filter displaced gases and monitor the system via supplied support skids or trailers. Figure 1 shows a typical MSU system set-up and a photo of a fillhead in operation at the Idaho CPP-603A Project in 2006.

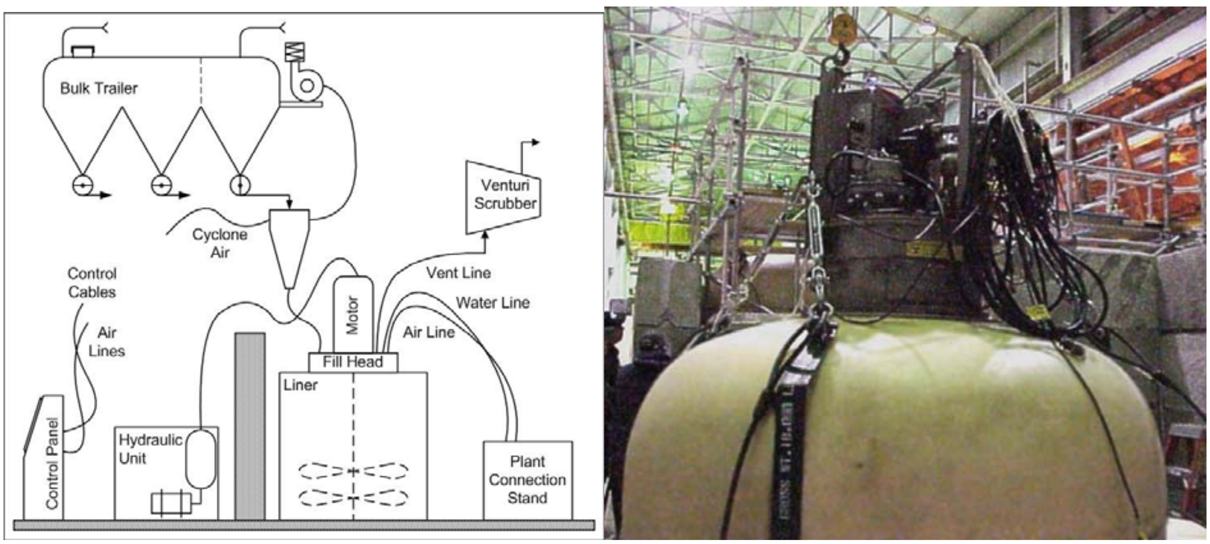

Fig 1. A typical MSU system set-up and a fillhead in operation at the Idaho CPP-603A Project in 2006

The following major components are typically included in these solidification systems:

- Liners. A steel container or HIC with an internal sacrificial shaft and paddle mixing assembly. All waste conditioning and solidification chemicals are added and mixed in the liner.
- The Fillhead Assembly. This seals onto the liner lid aperture and facilitates waste and chemical addition during the solidification operation. The fillhead contains piping for dewatering, waste addition, venting, cement and chemical addition, plus a hydraulic mixing motor which drives the liner mixer shaft. The fillhead also includes instrumentation and a camera for monitoring the solidification process within the liner.
- Plant Connection Stand. The plant connection stand is a portable unit containing an automatic waste shutoff valve, a dewatering pump and sampling, flushing, service water and service air connections.
- Venturi Scrubber. The liner is vented through the fillhead ventilation connection to a venturi scrubber unit. The venturi scrubber uses a water spray to remove drum ventilation dusts. The outlet of the venturi scrubber is connected to either the plant off gas system or a skid mounted HEPA filter assembly.
- Hydraulic Unit. This powers the mixer motor located on the fillhead.
- Control Panel. The control of waste, water, additives and cement addition; and of mixing operations are all remotely performed from the operator control panel. The control panel also provides the operator with all indications and alarms necessary for the safe, remote operation of the entire cementation system.

- Bulk Trailer. The dry chemicals (cement, lime and other cementitious materials as appropriate) required for waste solidification are stored in the bulk trailer. The system is designed to eliminate dusting by utilizing a baghouse or cyclone separator. An optional silo may be used in place of the bulk trailer for long-term applications. Electronic load cells monitor the amount of material transferred.
- Conveying Systems. The dry solidification chemicals transfer to the fill head via a pneumatic conveyor, designed to entrain other dry chemicals through a cyclone separator. This system minimizes the amount of dust and air that enters the liner by returning air from the cyclone separator back to the bulk trailer.

To ensure product quality, Energy*Solutions* has developed, tested and qualified a Process Control Program (PCP) for these solidification processes which meets 10CFR61 stability requirements for Class B and C wastes. This PCP has been approved to provide an acceptable waste-form, within both polyethylene high integrity containers (HICs) and steel liners for final disposal by the South Carolina Department of Health and Environmental Control (SCDHEC).

The solidification process begins with the PCP which ensures that each batch of radioactive waste received by the process unit is capable of being solidified into the desired end product – generally a monolithic solid matrix containing no free water.

Careful selection of additives in the PCP ensures control of pH, matrix strength, leachability, waste to end product ratios, heat generation, prevention of "bleed" liquid, and therefore this activity is instrumental in controlling and adjusting cement setting times.

The PCP allows a predictable end product and results in a strong concrete billet meeting all acceptance criteria for burial. The liner is prepared by installing temperature detector leads and a level measurement tube which connects to the fillhead. The liner is then placed in the process area in a shipping cask or shield (if required) and the fillhead/skirt assembly is lowered onto the liner. The hydraulic motor shaft engages with the disposable mixer paddle assembly to provide the agitation required. If required, a dewatering leg is connected to remove excess water.

After pre-operational testing of the system, the plant pump transfers radwaste into the liner from the plant waste connection via an automatic shutoff valve, waste hose and the fillhead assembly while the operator remotely monitors progress via the fillhead camera and lights. Should dewatering of the waste be required at this point, it is accomplished by mechanical filtration through disposable filters in the liner. Waste solids are removed from the sluice water, and retained by these filters and excess water is returned to the plant.

Once the waste transfer and any dewatering is complete, the hydraulic system is started and waste agitation begins. At this point, should pre-treatment of the waste be appropriate, additives are remotely added to the liner and thoroughly mixed with the waste in a manner specified by the PCP.

Solidification dry chemical addition is then started using the pneumatic conveying system. The dry chemical is continuously weighed with an instantaneous read out on the control panel allowing the predetermined quantity to be accurately added to the liner.

During solidification operations, the formation of cement is a complex, heat-generating procedure in which several different stages occur. The first, a gel state, is a rapid reaction and is normally completed in the first 24 hours of cure time. During the next several days, continued hydration reactions will occur to further increase the product hardness. The exothermic reaction can be mitigated by using other pozzolanic materials such as flyash and ground granulated blast furnace slag.

The formulas that produce structurally sound and free-standing cement billets vary according to the type of waste being solidified. Process variables accounted for include:

- Waste temperature
- pH
- Chemical composition
- Waste to cement/binder ratios
- Waste volume

These are carefully analyzed and controlled within the constraints of the PCP, by Energy*Solutions* field technicians who have extensive practical experience in waste solidification.

After the required cure time has elapsed, the fillhead is removed, the liner contents are inspected and if required, a penetration test is performed to confirm product quality before the liner is sealed for shipment. Strong, stable concrete billets are properly cured 36 to 72 hours after solidification and are then suitable for transportation.

Prior to commencing a cementation campaign at a customer's facility there are a number of key interfaces which must be identified and resolved such as processing space requirements; provision of utilities; local operating restrictions and procedures; availability of lifting equipment with sufficient capacity and headroom; Permit to work authorizations; establishments of controlled areas and areas designated for PCP test samples; Health Physics support; Waste Acceptance Criteria and shipping package identification; waste type classification and estimated chemical and radiometric analysis etc. Energy*Solutions* have developed many procedures to help customers navigate this list of interfaces and so avoid impacts to cost or schedule due to programmatic oversights.

MOBILE SOLIDIFICATION SYSTEM (MOSS)

The MOSS system was first designed by Westinghouse of Sweden [1] over 20 years ago and the system has been used at 8 facilities in 4 European countries to dispose of various wastes, often by moving units from facility to facility (See Figure 2a and 2b). Energy*Solutions* have negotiated exclusive rights to develop, fabricate and operate MOSS in the North American continent.

Fig2: a) and b)MOSS variants in use in European Facilities, c) Hanford K-Basin MOSS at Factory Test

The MOSS concept is based on the philosophy of fitting all the drum and cementation handling operations in one compact unit isolated from personnel by appropriate shielding. The system fits in a 6.1 x 2.4 m (20 x 8 feet) shipping container and processes 200 liter (or 55 gallon) drums, performing all cementation processes within this container, before returning the drums to their host facility. The wastes suitable for processing are those that exhibit moderate levels of gamma radiation and low levels of alpha activity and have included:

- Powdered ion exchange resin
- Ion exchange resin beads
- Evaporator bottoms
- Sludges and laundry waste
- Filter aids and sand

When the MOSS skid is delivered to site it typically comprises the main unit in a shipping container and a separate control desk which will be placed outside the shielded area. The equipment within the shipping container includes the following sub-systems:

- A drum trolley capable of horizontal travel and vertical elevation motions
- A series of stations comprising "heads" which interface with the waste drum
- A local ventilation system including a coarse baghouse filter, which ventilates the drum at the waste addition and cement addition and mixing locations
- A cement day tank with sufficient cementitious material for one day's drum production
- Cement additive dosing tanks and pumps
- A drip pan and trolley rail system including a Drum Loading Station (porch) to land the drum on prior to entry to the MOSS container
- A hydraulic power unit for the trolley elevation motion
- All necessary service and power connections
- MCCs and instrument control panels

- Close Circuit Television (CCTV) Cameras
- All necessary instrumentation to communicate with the control desk to ensure safe operation of MOSS
- A structural frame to support all of the above

Figure 3 shows a schematic diagram of MOSS. Only one drum may be in MOSS at any one time. Like other Energy*Solutions* cementation systems, MOSS utilizes drums with internal lost paddles. The MOSS cementation sequence is as follows:

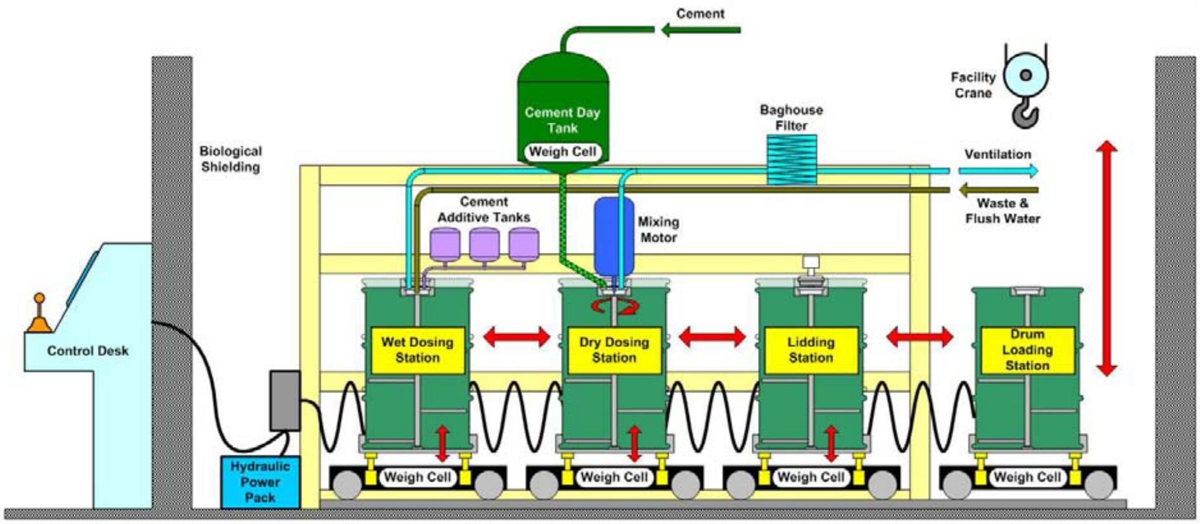

Fig 3: MOSS Schematic Diagram

- The drum is lowered onto the trolley parked at the porch (drum loading station)
- From the drum loading station, the drum is traversed into the container, stopping at the lidding station.
- At the lidding station, the trolley elevates to engage with the lid removal tool. This tool unfastens and retains the lid. The trolley lowers and traverses to the wet dosing station.
- A ventilated drip tray located at the wet dosing station is normally extended to catch drips from the waste feed line. On arrival of the drum it retracts to allow the drum to elevate and for waste addition to commence. Throughout the waste addition process the drum is ventilated with a “critical velocity” being drawn across the lip of the drum to minimize the escape of contaminants. On completion of waste addition, any liquid cement additives are added and the pump and line are flushed with water. The drum is then lowered, the drip tray is extended and the drum traversed to the dry dosing station.
- A ventilated drip tray located at the dry dosing station is normally extended to catch debris from the cement feed line and mixer drive. On arrival of the drum it retracts to allow the drum to elevate for mixer shaft engagement and cement addition to commence. Throughout the cement addition and mixing process the drum is ventilated with a “critical velocity” being drawn across the lip of the drum to minimize the escape of contaminants. On completion of the mixing cycle, the drum is lowered, the drip tray is extended and the drum traversed back to the lidding station.
- At the lidding station the drum is raised and the lid is reattached enclosing the cemented product in the drum. The drum then traverses to the drum loading station where it is removed by the crane to a suitable cement curing area. After curing, the drum would normally undergo a swabbing and monitoring operation prior to storage.

Like all waste cementation systems it is important to select the specification of the cementitious materials and additives according to the properties of the waste to be processed. Energy*Solutions* works with clients to develop recipes to meet their needs and validate this, as necessary, with appropriate testing using waste simulants. The parameters developed during these tests can then be programmed into the MOSS control system to ensure consistent product quality for each drum produced.

Energy*Solutions* modified MOSS for grouting of Hanford K-Basin sludges (See Figure 2c). The K-Basin MOSS unit was arranged to receive legacy reactor fuel sludges. Prior to cementation these sludges would have undergone a wet oxidization process to preclude the presence of Uranium metal in the grouted product and hence minimize in-drum hydrogen generation.

Due to the nature of the waste, this application had a higher potential for operators to receive radiation doses, principally through plate out in piping systems and from airborne activity from the low concentrations of Transuranic elements within the waste.

For ALARA reasons, it was therefore decided to relocate a number of maintainable systems, normally located in the MOSS skid, to locations adjacent to the skid, or outside the shielded area. These items included the electrical panels, the ventilation baghouse and the hydraulic power pack.

Although this system successfully passed its Factory Acceptance Testing (FAT) in 2005, and the product drum passed DOT7A testing, the unit was never put into active operation due to concerns about the performance of the wet oxidation process.

CANYON INTERMEDIATE LEVEL WASTE PROCESSING PLANT (CILWPP)

CILWPP is the encapsulation module of the British, Hunterston A Nuclear Power Plant's, Wet Intermediate Level Waste (ILW) Retrieval and Encapsulation Plant. The system was recently delivered to Hunterston after successfully passing its Factory Acceptance Test.

CILWPP was adapted from the MSU concept with added remote features for use with the Hunterston waste-forms which, due to their radiometric composition, cannot practically be encapsulated using hands-on equipment. CILWPP is a modular system and its "open canyon" design allows operations to be performed remotely via specialized tools and the facility's 10t overhead crane. The system can be, and was, pre-tested off site, for quicker facility installation and commissioning. It is designed to accept UK National Decommissioning Authority approved $3m^3$ drums (See Figure 4a), perform all cementation processes and return the drum to the host facility, however the design could be readily adapted for other waste package geometries. CILWPP employs modular shielding blocks around the encapsulation equipment but has no ceiling overhead making it only suitable for applications where the waste stream emits low to moderate levels of gamma radiation and where airborne activity is not a significance issue.

The process receives and encapsulates the waste in a cementitious grout, verifies grout set, adds a cold capping grout, swabs the drum around the lid flange for contamination, lids the drum and handles the product drums.

CILWPP comprises the following stations as illustrated in Figure 5a:

- Load-In Station – Where pallets and empty drums are sequentially loaded in
- Fill Station – Where liquid waste, followed by cement powders are added and mixed together
- QA Station – Where bleed water may be removed and verification of grout set is performed
- Capping Station – Where the waste grout is capped with inactive grout
- Lidding Station – Where lids are fastened to the drums and the drum is swabbed and monitored
- Spare Station – Where pallets are removed to be recycled to the load-in station

Intermediate Bulk Containers (IBCs) located outside the shielding, supply lime and cementation powders sequentially through a common powder fill line. Likewise other support systems such as the hydraulic power pack and, capping grout mixer, instrument rack and lid grapple are located outside of the shielded canyon.

All drums sit on top of pallets which are loaded into CILWPP in advance of the empty drums. A hydraulic ram acts on the nearest pallet to advance all drums in concert through the encapsulation process, with proximity switches providing positional feedback. Typically four drums at a time are indexed in this manner from station 1 through 4 to station 2 through 5, whereupon the ram is withdrawn, a new pallet and drum are imported, and the recently lidded drum is removed. CILWPP is capable of encapsulating two drums per 8 hour shift.

When a drum arrives at the **Fill Station** (See Figures 4b and 5b) the fillhead is in its raised position and a drip tray, is in place to prevent drips from contaminating the drum, pallets, or the floor. As the fillhead drive operates to lower the fillhead it also causes the drip tray to retract allowing the fillhead to seal onto the drum and engage the drive motor shaft with the drum paddle shaft. One proximity sensor determines the fillhead up position and another one indicates that it has correctly engaged with the drum.

The solidification process commences by adding waste to the drum in the form of sludge slurry, resin slurry, or neutralized acid. Load cells monitor the weight of the drum providing feedback on the amount of materials added.

Following waste addition, hydrated lime powder is added to the waste to condition it followed by appropriate quantities of two dry mixtures of Ordinary Portland Cement (OPC) and Pulverized Flyash (PFA); and OPC and Blast Furnace Slag (BFS) powders to effect solidification. All powders are delivered via the powder conveyor system while the drum paddle is driven by a compact hydraulic motor to provide the required torque to mix the drum contents for a duration and at speeds pre-determined by the operator. The entire drum filling operation takes less than four hours.

Fig 4: CILWPP FAT Photographs a) $3m^3$ RMWD drum b) Filling Station c) Capping Grout and Lidding Stations

A local ventilation system at the fillhead is in continuous operation regardless of fillhead position, exhausting through a common vent header to dedicated HEPA filters before being discharged into the main facility ventilation system. The fillhead also features various air and water rinse capabilities, and a camera with auxiliary lighting to view the solidification process in the drum as it occurs. Redundant ultrasonic level detectors are provided to minimize any possibility of overflow.

A **QA Station** utilizes a CCTV camera and a penetrometer to verify the proper solidification of the waste after a minimum curing period of 16 hours. The first drum of the day advances to the QA Station immediately following filling. This drum is allowed to cure overnight prior to testing. The second drum filled each day is allowed to cure in the Fill Station in order to meet its curing time requirement. The QA Station allows the drum to pass beneath it without touching the drum and a tie-in to the local ventilation system ensures an engineered capture velocity of 1 m/sec around the perimeter of the drum flange.

Prior to the penetrometer test, the grout surface is visually inspected using the local CCTV camera and any significant amount of bleed water is removed and pumped to the following drum at the Fill Station. The penetrometer is slowly pushed by a pneumatic cylinder against the top surface of the grout. The force exerted on the grout is indicated on the penetrometer gage, which can be read by the operator from another CCTV camera to verify whether the reading is above a prescribed acceptable value for the waste product.

The **Capping Station** (see Figure 4c) contains equipment to visually inspect the surface of the solidified waste; to observe the progression of the addition of a layer of non-radioactive capping grout; and to provide for ventilation. The capping grout serves to provide structural integrity to the drum for stacking purposes and also locks-in any potential contamination released from the active grout.

The Capping Station contains an ultrasonic level detector for determining the grout level in the drum. Two lines (dedicated and spare) are provided for grout addition. These feed lines are comprised of a flexible Tygon® inner hose surround by an outer flexible, poly-lined hose to facilitate inner hose removal/replacement. The expansion characteristics of the inner hose are desirable when cleaning the line with pressurized air before and after grout pumping with the line expansion also tending to keep the lines clear of hardened grout.

The drum lid is introduced and fastened on to the drum at the **Drum Load-out/Lidding Station** (see Figure 4c); the drum package is verified to be free of external contamination; and the drum is removed from the system. A lid with mounting bolts is fed manually into a lid grapple suspended from a jib crane which swings the lid over to the drum. The lid grapple is keyed so that the lid cannot be misaligned with the drum, while sleeves on the grapple retain the bolts. A pair of manipulators viewed by CCTV cameras aid placement of the lid, and the lid bolts are tightened using a computer controlled nut runner designed to both measure and control torque.

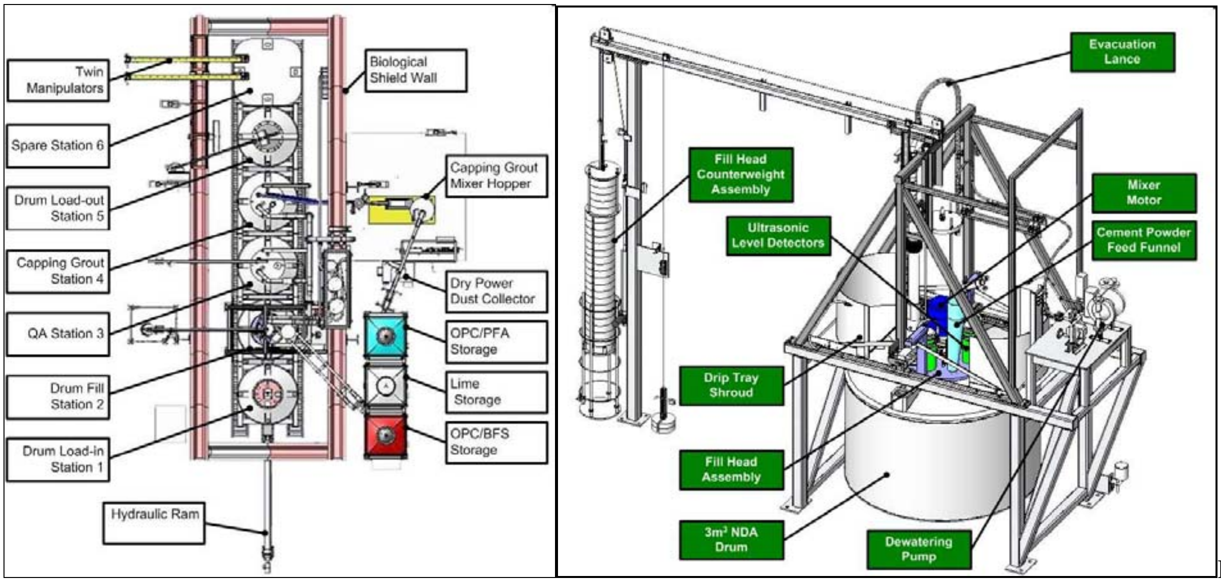

Fig 5. a) Plan view of CILWPP Showing Key Equipment, b) Diagram of CILWPP Fillhead Assembly

The manipulators are then used to obtain a swab of the area around the lid to verify drum cleanliness. This swab is passed through a swab transfer tube, where the operator manually removes it for analysis. If the swab check is acceptable, the drum can then be removed using the overhead crane and placed in the cross-site transporter. If the swab check is not acceptable, the drum is removed using a Secondary Containment Vessel (SCV) at the Spare Station as described below. Following removal of the drum the empty pallet is pushed to the Spare station.

The pallet is removed at the **Spare station**, using the overhead crane to be returned to the Load-in station. The Spare Station is also used to place drums into the SCV, if required. Using the overhead crane, the SCV is placed into the Spare Station, its lid is removed and the compromised drum is loaded into the SCV, which is relidded and the entire package transferred to the facility truck bay for sentencing.

Although the Spare Station is not intended for routine drum storage, it also allows one more storage location for completed drums, if necessary, to decouple drum production from any scheduling issues, which may arise, with the cross-site transporter operations.

MODULAR INTERMEDIATE LEVEL WASTE PACKAGING PLANTS (MILWPP)

MILWPP is a conceptual design for Solidification of the B30 Spent Fuel Sludge waste at Sellafield, UK. Whereas, Hunterston is a Nuclear Power Plant with relatively benign corrosion product sludges in its fuel pool, B30 is a legacy early generation fuel decanning facility for the UK Magnox Reactor’s Uranium metal fuels. As a result the sludges in B30 are rich in Uranium metal and fission products from the decanning processes and Uranium Oxide from corrosion, as a result of the long underwater storage of the fuel at the facility. Handling and grouting of this waste is therefore a significant challenge.

MILWPP as shown in Figure 6, utilizes similar equipment to CILWPP, however this equipment is located inside a cell made of transportable modules each comprising of walls and a ceiling which when combined form a structure with can be suitably ventilated to provide radiation shielding and contamination confinement, therefore making it suitable for treating the B30 waste which is high in both alpha and gamma emitting radionuclides.

Enhancements over CILWPP include:

- A fully enclosed, ventilated cell arrangement protecting operators from the waste but allowing most equipment to remain external to the shielding and so be readily accessible for maintenance.
- A swabbing and monitoring station featuring Nitrocision® high pressure Nitrogen gas decontamination lances. It should be noted that the need for swabbing of the drum sides, results in irregular drum spacing, which in turn invalidated the adoption of the CILWPP hydraulic ram indexing system.
- Two independent trolleys which elevate the drums to the various heads. These trolleys work in concert with a pair of channels running the length of MILWPP allowing the trolleys to lower, park their drums and

traverse to service other drums. The two trolleys ensure that the two drums which at any one time are undergoing active operations are always raised up to the ventilation heads, except during transfer to the next station. This minimizes the potential for contamination of the MILWPP interior.

- Out of specification storage areas are utilized to prevent problematic drums holding up production while operators sentence out-of-specification units.

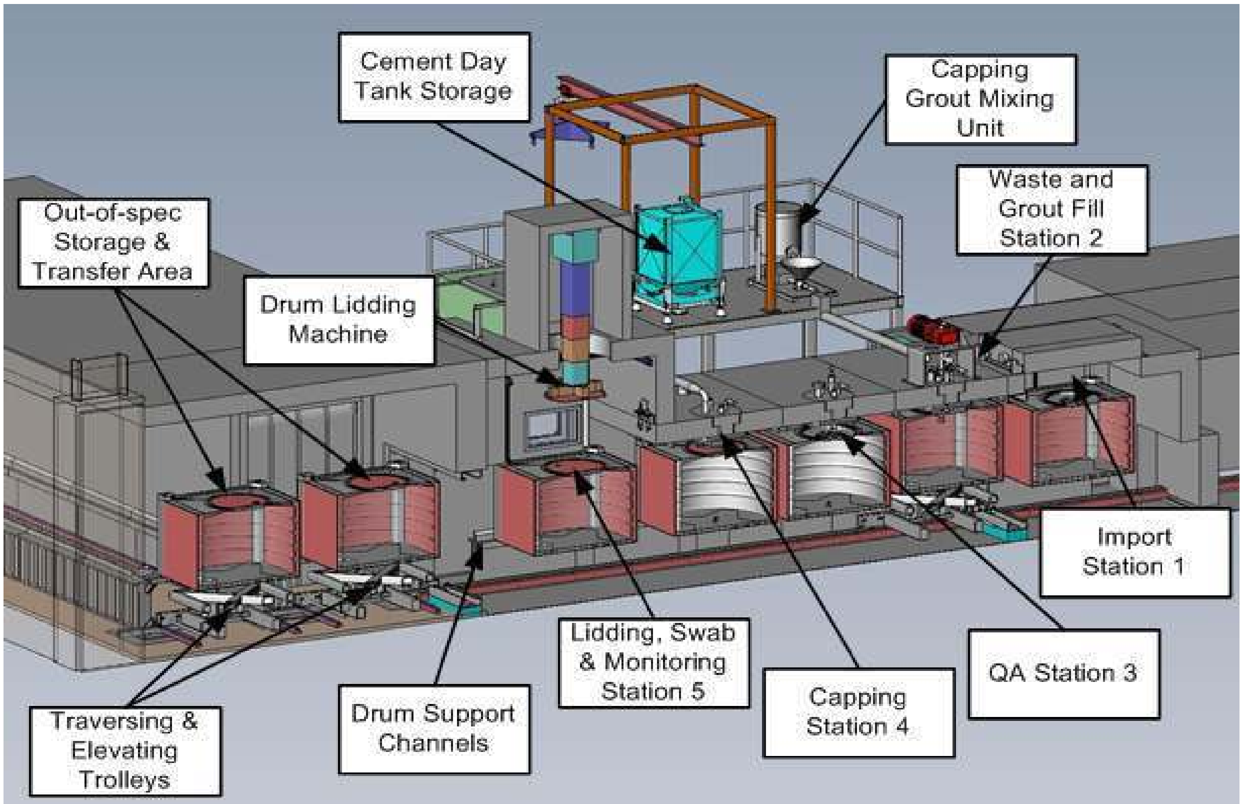

Fig 6: MILWPP Conceptual Design

The Sellafield facility operator is currently re-evaluating the strategy for disposition of the legacy wastes in B30 and as such the MILWPP design has not yet been developed to a detail design level.

GLOVEBOX CEMENTATION MIXING SYSTEMS (GCMS)

GCMS uses a lightly shielded but highly confined glovebox. By the use of a patented combined bagless transfer and mixing drive, this glovebox accepts 55 gallon drums, performs all cementation processes and returns them to the host facility without spreading alpha activity. This system can be permanently installed in facilities where an ongoing process is in place, or conversely is compact enough to permit mobile use.

Figure 7a illustrates one of four glovebox assemblies Energy*Solutions* is currently fabricating for Savannah River Nuclear Solutions (SRNS), for use at the Savannah River Site (SRS) Waste Solidfication Building (WSB). This facility will accept, Low Active Waste (LAW) and High Active Waste (HAW) effluents from two new facilities: the MOX Fuel Fabrication Facility, and the Pit Disassembly and Conversion Facility, and solidify them into a cement matrix within 55-gallon drums [2]. After some on-site interim storage the HAW and LAW drums will be dispatched for final disposal to the Waste Isolation Pilot Plant in New Mexico and the Nevada Test Site respectively.

In WSB, the wastes undergo relatively simple processing including evaporation to reduce waste volumes and neutralization to raise the pH of the acidic waste streams. After neutralization, the wastes are fed to a suite of four dedicated gloveboxes, where the waste is stabilized without loss of confinement.

Working very closely with SRNS and the Savannah River National Laboratory (SRNL), Energy*Solutions* has completed four key stages of the project : Conceptual Design, Proof of Principle Testing, Detail Design and Waste

Envelope Determination Testing; and is currently working to complete fabrication, assembly and factory acceptance testing to ensure an equipment delivery to SRS by Spring 2011.

When embarking on the **Conceptual Design** of the WSB gloveboxes, Energy*Solutions* recognized that there were three key issues that needed to be addressed:

- Protection of operators from the high-alpha inventory of the HLW waste stream.
- Meeting client drum cleanliness requirements.
- Satisfying the client's requirement to add liquid waste to drums pre-filled with dry cementitious material. This approach is contrary to the order of addition in typical nuclear cementation systems[2] but has the significant advantage of removing the need for complex active cement addition facilities, which in turn minimizes the cement dust entrainment challenge to the facility ventilation system.

As Energy*Solutions* had significant experience with confinement of similar wastes at various facilities it was determined that the first two issues could be addressed by careful design that drew on that previous experience. The key innovative feature of the GCMS, which currently has a pending US Patent [3], is the incorporation of an integrated bagless transfer coupling, waste fill line, and cementation drive between the glovebox's primary confinement, and the waste drum. This bagless transfer confines the highly active waste solely within the drum and the primary confinement; and therefore ensures that the exterior of the drum and the interior of the secondary confinement surrounding it, are segregated from the waste throughout the drum positioning, filling and mixing processes.

Energy*Solutions* determined that the third issue could only be minimized by focused development work, and prior to submission of their proposal to SRNS, confirmatory trials were performed to ensure the feasibility of the cementation mixing technique envisioned. This work was performed sequentially at 2-gallon, 5-gallon and finally full-size 55-gallon scales. During these trials preliminary mixing parameters were developed, including torque, speed, duration and a suitable "D-paddle" mixing design, as illustrated in Figure 7b, was evolved. The success of

Fig 7: a) A GCMS Glovebox Being Fabricated, b) Developed GCMS D-paddle

these tests, allied with the proposed confinement design concept, were key differentiators leading to the client selecting Energy*Solutions* to design and manufacture the GCMS systems.

[2] To minimize mixing torques and avoid cement "dough-balling" problems it is normal practice when grouting nuclear waste to add the waste to the drum and then gradually stir in the dry cement materials.

After completion of conceptual design, a **Proof of Principle Testing** program was performed. Building on the success of the pre-contract testing, full-size formal NQA-1 controlled testing was performed [4] using a prototypic test rig in accordance with client specifications, which included the following:

- Waste simulant and actual cement chemistry trials in accordance with client recipes for LAW and HAW.
- Development of key parameters and techniques including: cement preparation methodology, waste addition rate, paddle torque, paddle speed, and mixing durations.
- Demonstration of robust drum clamping and sealing techniques during mixing.
- Demonstration of drum confinement effectiveness using powdered tracer dyes in the cement.
- Development of a replaceable off-gas roughing filter to protect the client's downstream HEPA filters from trace cement dust carried into the off-gas.
- Removing drum lids immediately after mixing to confirm good mixing of the cement and waste simulant.
- Monitoring drum temperature "exotherms" for 24 hours after mixing.
- Sectioning of drums to demonstrate that waste simulants were successfully incorporated into the cement matrix, that no excessive void spaces occurred and to confirm the absence of free liquid.
- Demonstration that the mixing cycle times meet the facility throughput goals.

All the testing objectives were met and the test program provided the necessary underpinning input data to allow detail design to proceed. One critical area was the waste addition flow rate and it's sequencing in relation to paddle speeds. Initial trials resulted in "dough-balling" of the drum contents causing the mixer drive to stall. However, after some optimization of the motor's Variable Frequency Drive settings and of the cement preparation, waste addition rate, and of various process step timings, a technique was developed which produced consistent conforming drums. It is important to note that this mixing technique meets the client's need to incorporate the waste without any free liquid, however it does not create a monolithic structure as it can leave small quantities of unreacted cement in the drum at a "tideline" above the top of the mixture. It is also not suitable in its current configuration, for applications where filling the drum in excess of 70% is required, although this could be addressed by the addition of an inactive capping grout procedure. However the benefits to SRNS of removing dry cement handling from the glovebox greatly outweigh these minor disadvantages.

The GCMS **Detail Design** evolved from the conceptual design and the lessons learned from the proof of principle testing. The system has three confinement levels (see Figure 8), which ensure that facility operators are not exposed to airborne or liquid radioactive waste and that the product drum exterior is kept free of contamination from this waste.

These confinements are:

- The primary confinement, which sits above the secondary confinement and is the means by which waste is introduced into the drum. This section of the glovebox will be potentially contaminated and operates at a gauge pressure of approximately negative 1.0-inch water column.
- The secondary confinement, which sits below the primary confinement and where a lift offers the drum up to the underside of the primary confinement. This section of the glovebox will not be contaminated under normal conditions and operates at a gauge pressure of approximately negative 0.7-inch water column.
- The transition confinement, which is provided by the inlet and outlet airlocks. These airlocks provide added security but on many applications are not likely to be necessary.

Surrounding air enters through inlet HEPA filters and cascades through these glovebox sections to the primary confinement and then exits to the WSB building ventilation system, which provides the depression required in the gloveboxes and features HEPA filters to remove radioactive contaminants prior to stack discharge.

Figure 8 also depicts the key mechanisms within these glovebox assemblies. The central innovative feature of the GCMS is the incorporation of an integrated bagless transfer coupling, waste fill line, and cementation drive between the primary confinement, and the secondary confinement and drum. This bagless transfer continuously confines the highly active waste within the drum which is only ever open to the primary confinement; and therefore ensures that the exterior of the drum and the interior of the secondary confinement are segregated from the waste throughout the drum positioning, filling and mixing processes.

The GCMS receives stainless steel lost-paddle drums pre-charged with dry cementitious material into its secondary confinement and remotely mixes radioactive waste, as it is fed through the fillhead, with the cement inside the drum.

The DOT-7A compliant drum features a screwed-on outer lid, and a pull-off inner lid which is an integral component of the bagless transfer coupling.

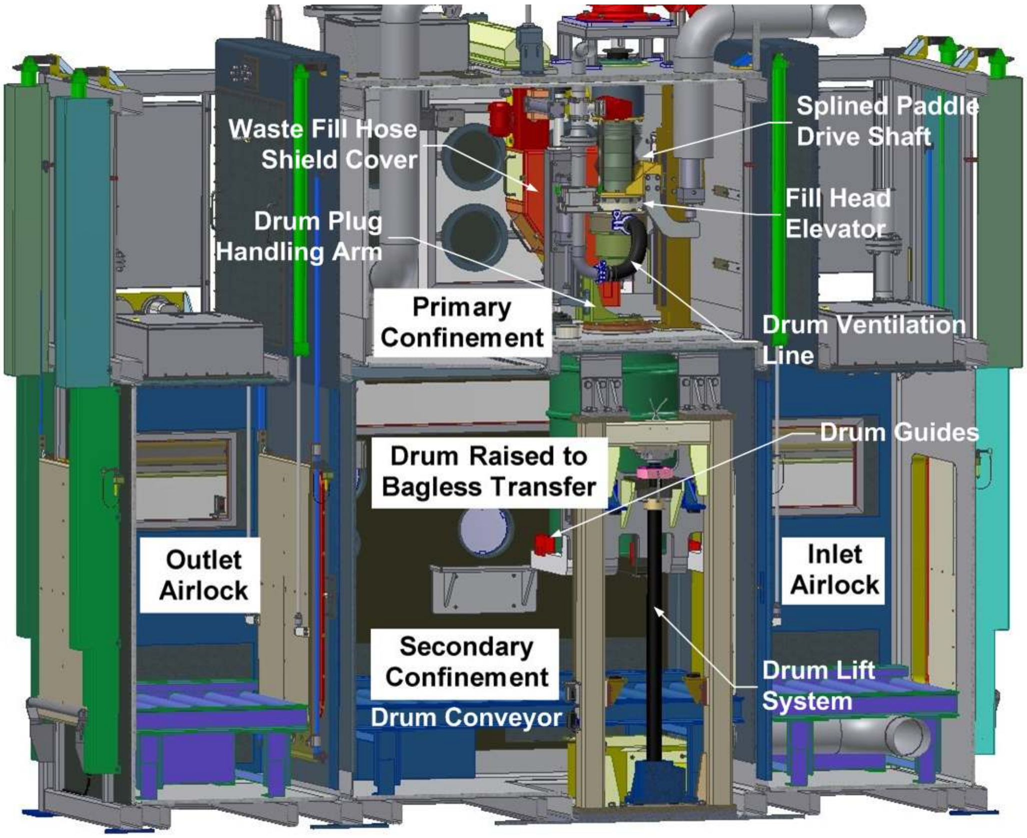

Fig 8: Diagram of GCMS Glovebox Showing Key Mechanisms

The primary confinement features a plug handling arm to remove and replace the central drum seal plug and a waste fill and mixing head to feed radioactive waste to the drum, provide ventilation to the drum during the filling and mixing process, and to drive the in-drum mixing paddle. Figure 9 illustrates the cementation process steps within GCMS once the drum is in place under the primary confinement as follows:

- The seal plug handling arm locking pin actuates, locking the plug handling arm onto the drum seal plug and the seal plug is elevated away from the drum (overcoming the resistance of the seal plug latching spring), and rotated clear of the bagless transfer port. At this stage, the drum internals are open to the primary confinement; however, both the exterior of the seal plug and of the drum are isolated from the primary confinement by elastomeric seals.
- The mixing head drive shaft starts rotating at low speed and the head is lowered to engage with the paddle shaft and then seal to both the drum and the primary confinement. The cementitious material is then “fluffed” by the paddle rotation in accordance with parameters developed during Proof of Principle Testing.
- Waste is then added in a similarly proven, preset manner and stirred into the cement for approximately 30 minutes to ensure homogeneity, minimize motor torque, and minimize dust carry-over to the off-gas system.
- The fill head is then raised and dwells for a few minutes, allowing any residual drips to fall into the drum.
- The drum plug-handling arm is rotated and then lowered back into engagement with the drum, and the seal plug-locking pin released. A drip tray on top of this arm ensures capture of any final pour head drips.
- Throughout this process the seal plug exterior and the plug handling arm underside have been mutually protected from the environment of the primary confinement by seals on the plug handling arm.

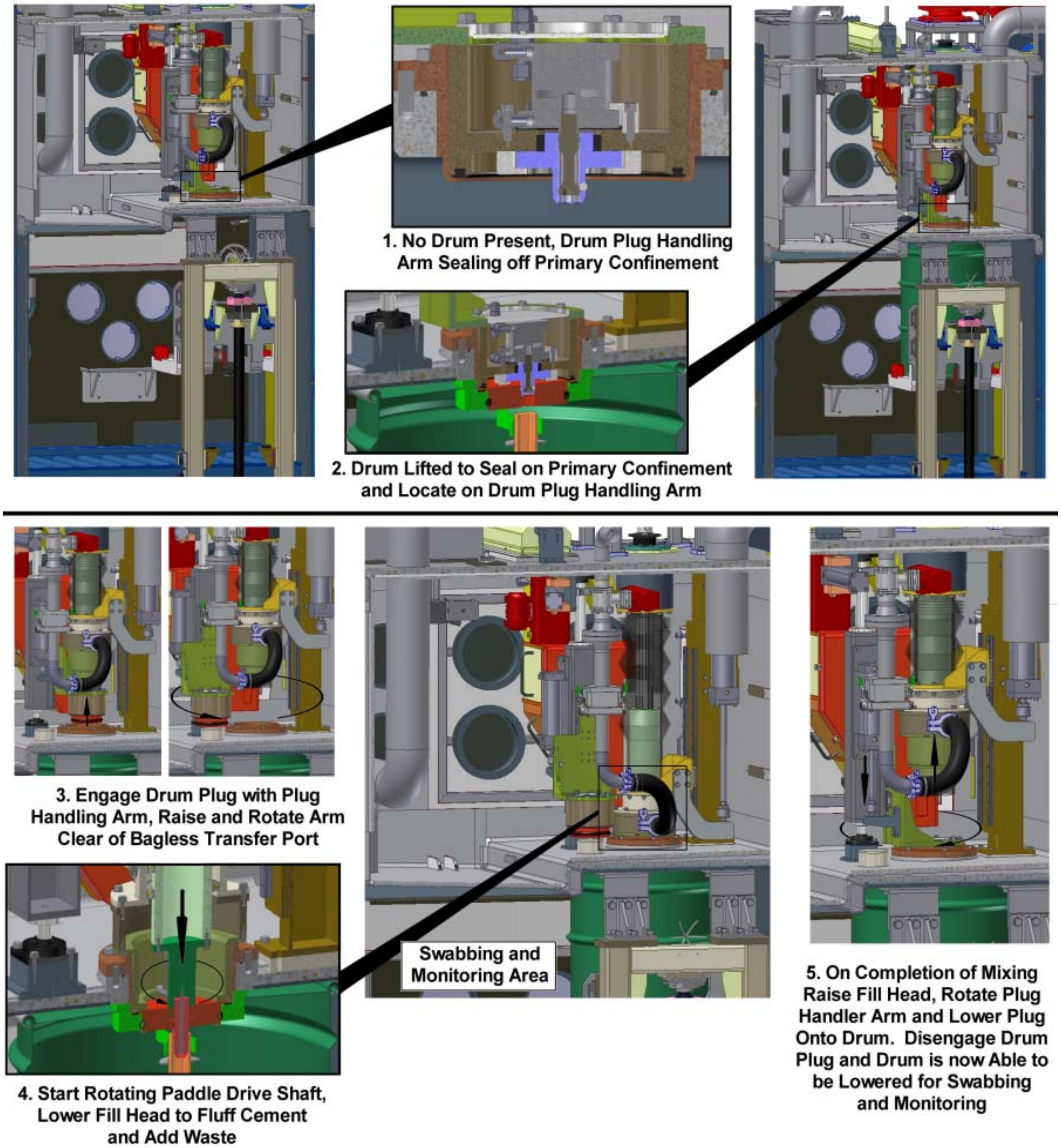

Fig 9: Key GCMS Glovebox Bagless Transfer Operations

During the Detail Design stage, SRNS requested that Energy*Solutions* perform additional **Waste Envelope Determination Testing** [5] to help SRNS and SRNL refine their upstream processes. These tests involved performing trials on the following recipes:

- The HAW baseline chemistry as tested in the Proof of Principle Testing
- A water and cement only test aimed at examining a significantly lower than baseline water/cement ratio
- Four HAW simulant chemistry variants from the HAW baseline
- A heated HAW simulant of the same chemistry as the baseline (to simulate no post neutralization cooling)

As anticipated the baseline drum was successfully mixed. As each more stringent test was performed the mixing motor torque readout reached higher peak levels as the process moved through the doughball phase, often exceeding the motor rating, and in the case of two of the HAW recipes causing the system to stall. These tests were highly successful to SRNS and SRNL in guiding them on how much margin is available to them in the chemistry of the waste delivered to GCMS and confirmed the need to cool the waste prior to cementation.

Fabrication of the GCMS gloveboxes is proceeding with the main confinements complete and the mechanical sub-assemblies currently being installed. **Factory Testing** will be performed in Spring 2011 when each glovebox pair will be set up alongside the drum handling system, which Energy*Solutions* also designed and fabricated. Six drums will be processed in each glovebox, with one of these six being emptied and inspected for paddle and drum damage and the other five being allowed to set for subsequent sectioning and inspection.

CONCLUSIONS

When contemplating a solidification mission, it is important to consider whether a fixed “monolithic” system is required or whether a portable system can satisfactorily meet the project needs. In particular where a facility already has available assets such as electrical power, utilities, cranes, ventilation, etc, it may be practical to temporarily install a portable cementation system to process the facility’s wastes and subsequently remove the system, all within a relatively short timescale. The advantages of this approach include minimizing design; easier regulatory approval due to the transient nature of the installation and reduction of risk by sub-contracting equipment supply, operation, decontamination and decommissioning (D&D) to a industry specialist contractor. The net effect of this is likely to be a significant overall reduction in mission lifetime cost and schedule.

Portable, modular cementation systems have been successfully utilized in the cementation of nuclear waste in both USA and Europe. The MSU and MOSS systems have both been used in multiple facilities often moving hardware from one facility, when the solidification mission is complete, to the next allowing very significant cost and schedule savings to clients. This approach avoids the wasteful exercise of designing one-of-a-kind systems and allows the lessons learned in earlier solidification campaigns to be leveraged for new projects. It also removes the need to perform D&D on facilities and equipment resulting in a reduction in secondary waste, as the cementation contractor will remove and decontaminate his equipment for reuse at other client’s facilities as soon as all the waste has been stabilized.

The development of cementation recipes can also be time consuming, requiring significant research and development programs. By leveraging proven, regulatorily robust programs such as the Energy*Solutions* Process Control Program these development trials can be greatly curtailed, again leading to significant cost and schedule gains.

Portable cementation system are now being applied by Energy*Solutions* to even challenging wasteforms such as fuel sludges or wastes high in alpha activity and although these systems have yet to establish a proven operational pedigree, they are built on the achievements of prior cementation systems and as such are expected to enhance the future prospects for this approach to waste solidification.

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