Cementation Mixing Gloveboxes for Radioactive Wastes at the Waste Solidification Building at DOE Savannah River Site – 10237

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ABSTRACT

Energy*Solutions,* Engineering and Technology Group, is providing the design, fabrication, and testing of four gloveboxes to safely stabilize High Active and Low Active Wastes arising from new demilitarization facilities under construction at the DOE Savannah River Site.

Using the proven "lost paddle" in-drum mixing technique, 55-gallon drums preloaded with dry cementitious materials receive and blend liquid waste with the cement to create a stable waste form. This approach removes the need to meter cement powders into the glovebox, reducing the burden on the glovebox ventilation system and minimizing active equipment requirements.

The Energy*Solutions* design team determined that to ensure continuous confinement of this highly active waste, it would be necessary to incorporate a bagless transfer coupling between the drum and the glovebox throughout the filling and mixing procedure. Accordingly, each glovebox comprises the following sections: A secondary confinement where the drum seals to the bagless transfer port; a primary confinement, where the drum seal plug is removed and the waste is introduced; a drum inlet airlock; and a drum exit airlock. Throughout the drum filling and mixing operation the drum exterior will be isolated from the potentially contaminated primary confinement. Gloveports in the secondary confinement allow for a swabbing and monitoring operation to confirm drum cleanliness and facilitate manual decontamination. Operations are generally performed from a local control station suitably positioned to ensure attainment of ALARA goals.

This paper describes how mixing techniques were developed and tested full-size, using the client's specified simulated wastes and cement recipes, to validate the cementation equipment arrangement and process, and describes the key features of the glovebox system design that have been developed, and is now currently being fabricated.

INTRODUCTION

The DOE/NNSA is currently constructing a suite of facilities at Savannah River Site, South Carolina, to convert surplus U.S. weapons-usable Plutonium into mixed uranium-plutonium oxide (MOX) fuel for use in existing domestic commercial reactors. One facility, the Pit Disassembly and Conversion Facility will disassemble the fissile cores of implosion weapons known as pits and convert them to plutonium oxide, creating some Low Active Waste (LAW) effluents in the process. A second facility, the MOX Fuel Fabrication Facility, will receive this plutonium oxide and combine it with uranium oxide to produce commercial MOX fuel, creating more LAW in addition to High Active Waste (HAW) effluents in the process. A third facility, the Waste Solidification Building (WSB), will take the effluents from the other two plants and solidify them into a cement matrix within 55-gallon drums. 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 dedicated Cementation Mixing System (CMS) gloveboxes, which form the subject of this paper. Figure 1 illustrates an overview of the WSB process.

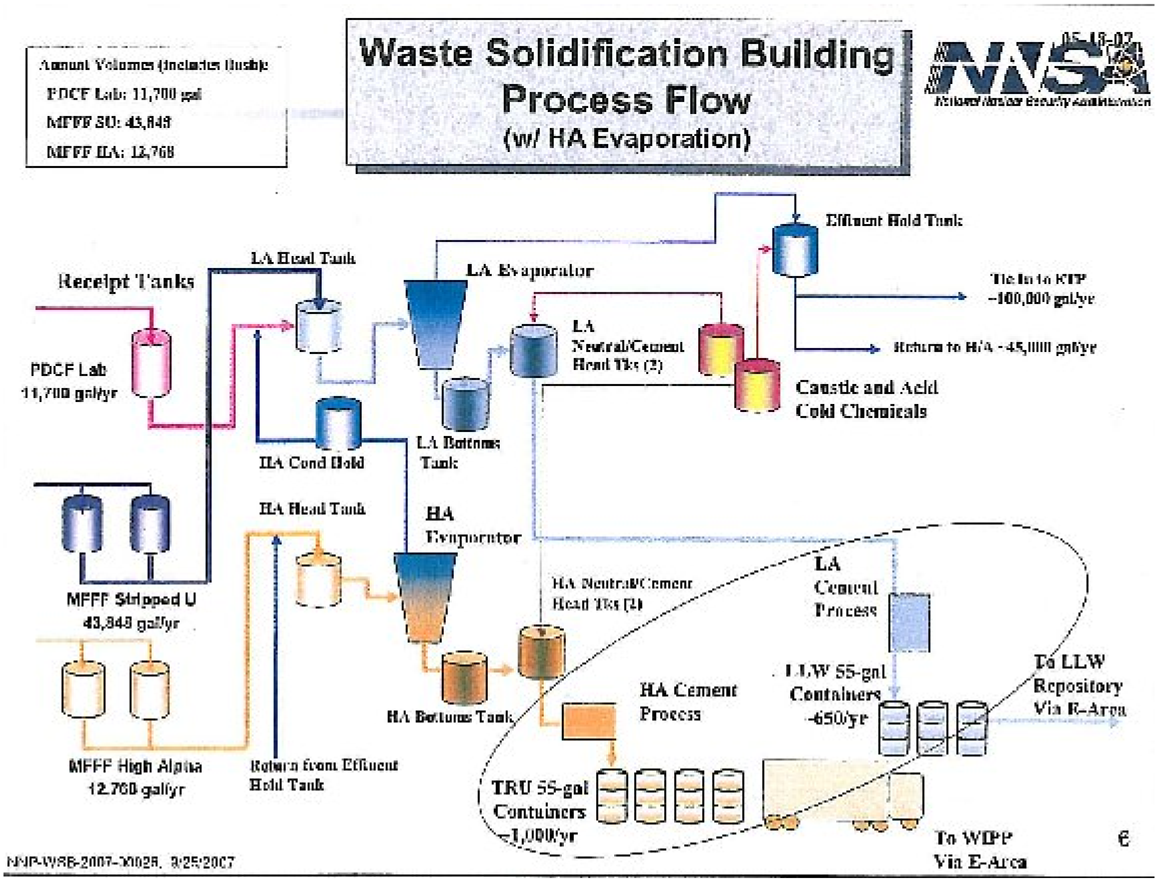

Figure 1: Waste Solidification Building Process Flow Overview

Savannah River Nuclear Solutions (SRNS) are responsible for the design, construction, commissioning and operation of WSB including the development and maintenance of the facility safety basis. SRNS have also developed cementation recipes with Savannah River Nuclear Laboratory for the solidification of the waste to ensure stringent waste compliance requirements can be met. SRNS have sub-contracted the development, design, fabrication, factory acceptance testing, delivery and installation support of the CMS to Energy*Solutions.*

Subsequently the contract scope has been extended to also include the design of a Drum Handling System which, along with CMS will be located in two similar discrete rooms – one for the LAW stabilization and one for the HAW stabilization. The typical arrangement of one of these rooms is illustrated in Figure 2.

The drum handling equipment comprises the following main assemblies in each waste processing room:

- An eight-position Drum Storage Conveyor for drums partially pre-filled with cementitious material.

- A single drum capacity battery powered Import Auto-guided Cart for importing drums into the cementation gloveboxes.

- A single drum capacity battery powered Export Auto-guided Cart for exporting drums from the cementation gloveboxes.

- A 12-position “Lag Storage Conveyor” where cemented waste drums cure.

- A control system with Human Machine Interfaces for manual and automatic control of this equipment.

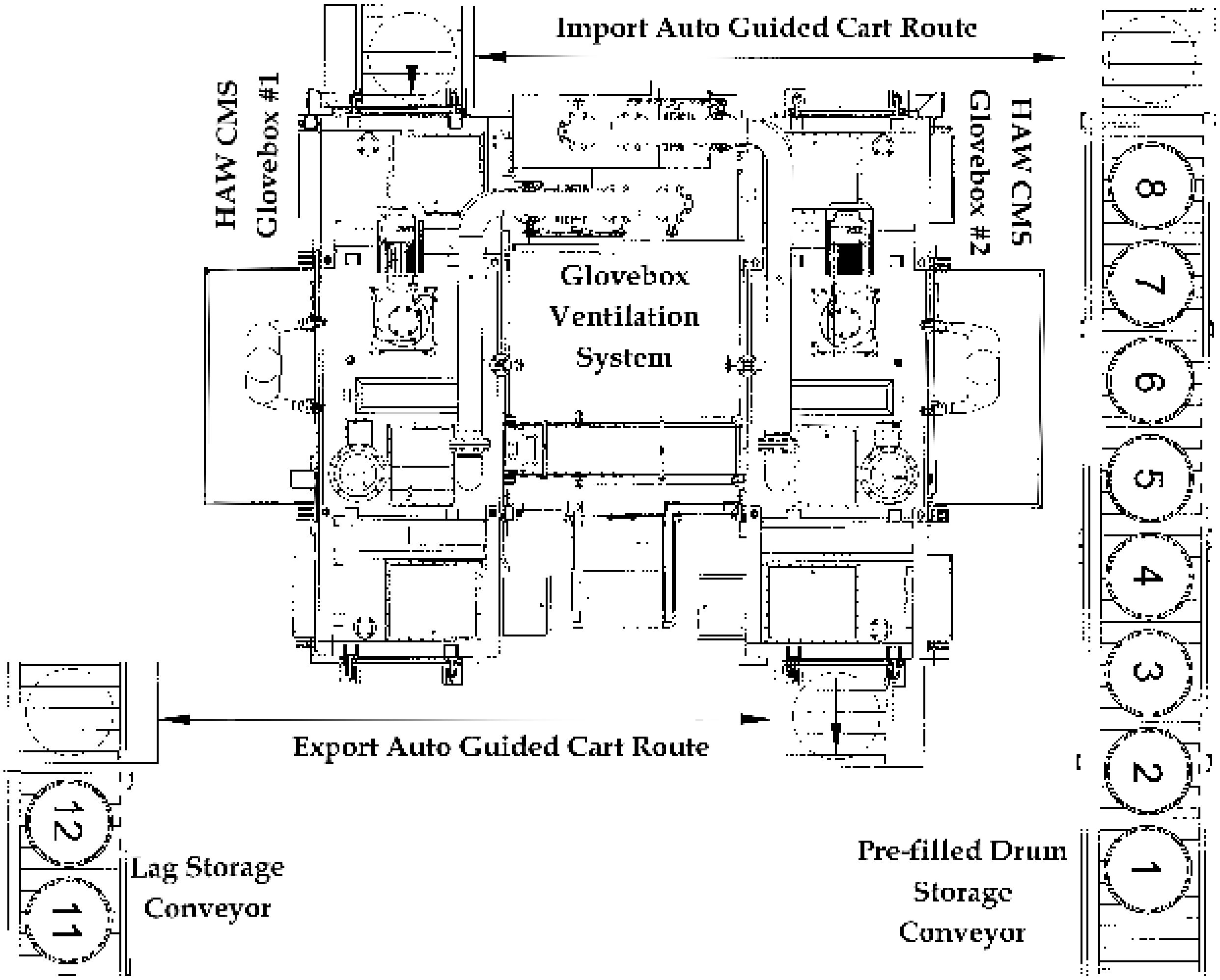

Figure 2: Layout of HAW Room Showing CMS Gloveboxes and the Drum Handling System

The CMS comprises two glovebox assemblies in each waste processing room each in turn consisting of:

- An inlet airlock, which receives drums from the import cart.

- A secondary confinement, which houses the drum during waste filling and mixing; and where the drum is checked for cleanliness prior to export.

- A primary confinement which docks to the drum using a bagless transfer port, directs waste into the drum, and drives the mixing shaft and in-drum paddle assembly.

- An export airlock, which dispatches filled, drums to the export cart.

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

- To protect operators from the high-alpha inventory of the HAW stream, a high integrity glovebox confinement system is required.

- To ensure client drum cleanliness requirements are met the segregation of the drum exterior from the HAW is crucial.

- The client's requirement to add liquid waste to dry cementitious material already within the waste drum is the reverse order from typical nuclear cementation systems suggesting the need for confirmatory prototypic development testing to be performed before detail design could commence.

This paper describes the methodology adopted to tackle these issues, the development trials performed to minimize technical risks, the proven design features adopted by the team, and the subsequent detail design of the system.

OVERVIEW OF CMS SYSTEM

Figure 3 illustrates one of the four CMS glovebox assemblies. The CMS receives stainless steel drums pre-charged with dry cementitious material, which by utilization of the "lost paddle[1]" process remotely mixes radioactive waste and cement within the drum, which is in turn housed within the glovebox secondary confinement.

These drums feature a screwed-on outer lid, designed to ensure DOT-7A compliance and a pull-off inner lid, which is an integral component of the bagless transfer coupling that ensures confinement control within the glovebox system.

The CMS system has three confinement levels, 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 approximately –1.0-inch water column.

- The secondary confinement, which sits below the primary confinement and offers the drum up to the underside of the primary confinement. This section of the glovebox will not normally be contaminated and operates at approximately –0.7-inch water column.

- The transition confinement, which is provided by the inlet and outlet airlocks.

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[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.

Room air enters the glovebox through carefully placed HEPA filters and cascades through the other glovebox sections to the primary confinement and then exits to the client's main building ventilation system. This building ventilation system provides the depression required in the CMS gloveboxes and features HEPA filters to remove radioactive contaminants prior to stack discharge.

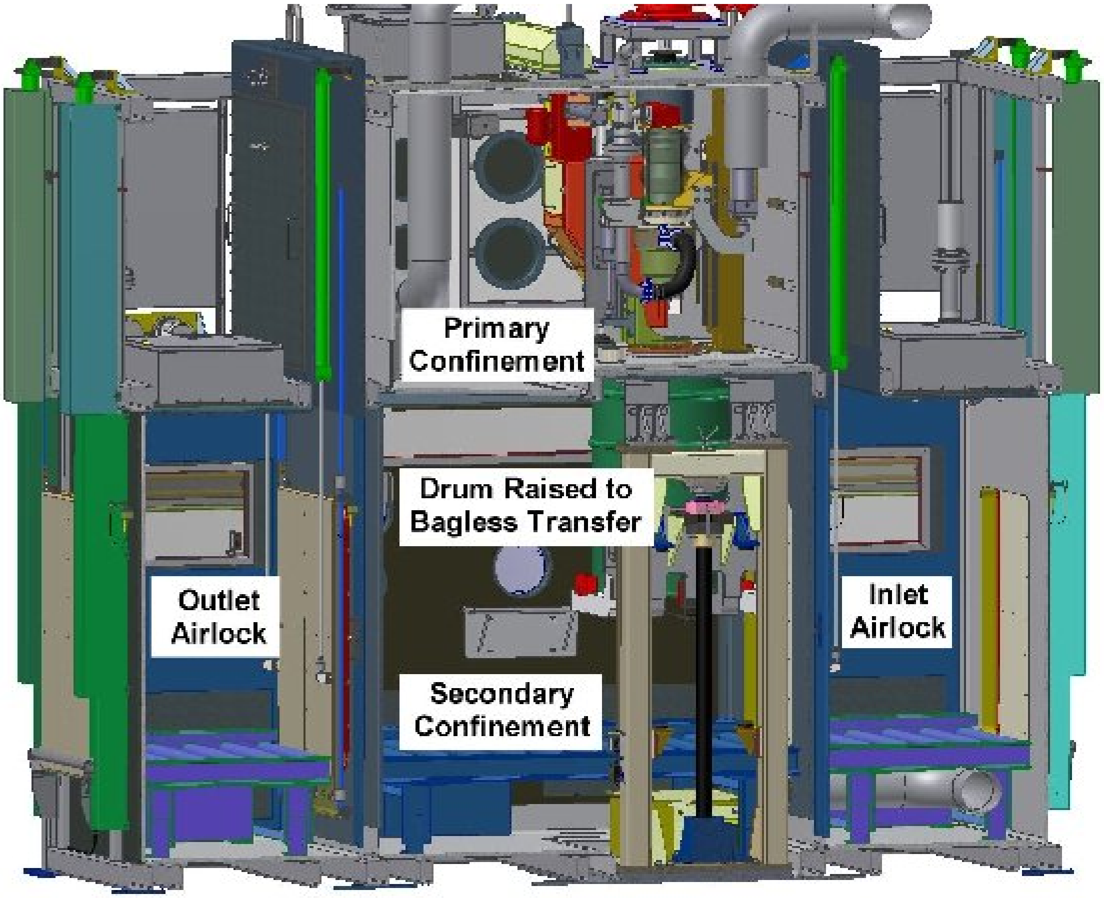

Figure 3: Diagram of CMS Glovebox

In addition, the facility vessel ventilation system sweeps a nominal 5cfm of air from the drum when the fill head is lowered, removing air displaced by the waste, Hydrogen gas generated by radiolysis, and ensuring any potential gas flows will always be from the glovebox into the drum.

The key innovative feature of the CMS, which currently has a pending US Patent [1], 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 continuous confines the highly active waste which is within the drum and is also potentially contaminating 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.

Figure 4 illustrates the various steps performed during the drum mating, filling, mixing, and lidding process. In developing the CMS, the design team combined three key elements from Energy*Solutions* suite of proven designs:

- A remote handling arm system adopted from the Sellafield and Hanford Waste Treatment Plant AutoSampling Systems. These remote handling systems have been utilized for over twenty years at Sellafield and have successfully opened hundreds of thousands of sample carriers, removed sample bottles, taken radioactive samples, and subsequently closed each carrier with the sample bottle inside with minimal cross-contamination.

- Drum design concepts from the Advanced Mixed Waste Treatment Plant at Idaho Falls, Utah, where thousands of Contact Handled Transuranic (CH-TRU) waste drums have been successfully filled with super-compacted TRU waste pucks over the last five years via a bagless transfer coupling fitted to the puck handling glovebox.

- Remote in-drum grouting from the Mobile Sludge Solidification System (MOSS)[2], a system which, has been utilized over the last fifteen years in several European facilities to successfully solidify a variety of different types of radioactive wastes.

Referring to Figure 4, the key CMS operations are as follows:

I. Secondary Confinement – Pre-Mixing Process

There are two stations in the secondary confinement – one where the drum is offered up by the drum elevator to the primary confinement above, to allow introduction of, and subsequent cementation of, the waste within the drum; and one that allows the drum to be manually swabbed and monitored to identify and, if necessary, to remove any contamination on the drum exterior (See operation III below).

a. The drum is lifted from the drum conveyor by the drum elevator to the ceiling of the secondary confinement chamber. This operation both seals the drum to the primary confinement and seals the drum inner seal plug to the seal plug handling arm that subsequently removes this plug. A load cell on the drum elevator ensures that a sufficient pre-load is maintained during the entire cementation process to maintain a sealing force and hold the drum in place during mixing.

b. The drum is now in position to receive liquid wastes.

II. Primary Confinement

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.

a. The seal plug handling arm locking pin actuates, locking the plug handling arm onto the drum seal plug and the seal plug is elevated 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.

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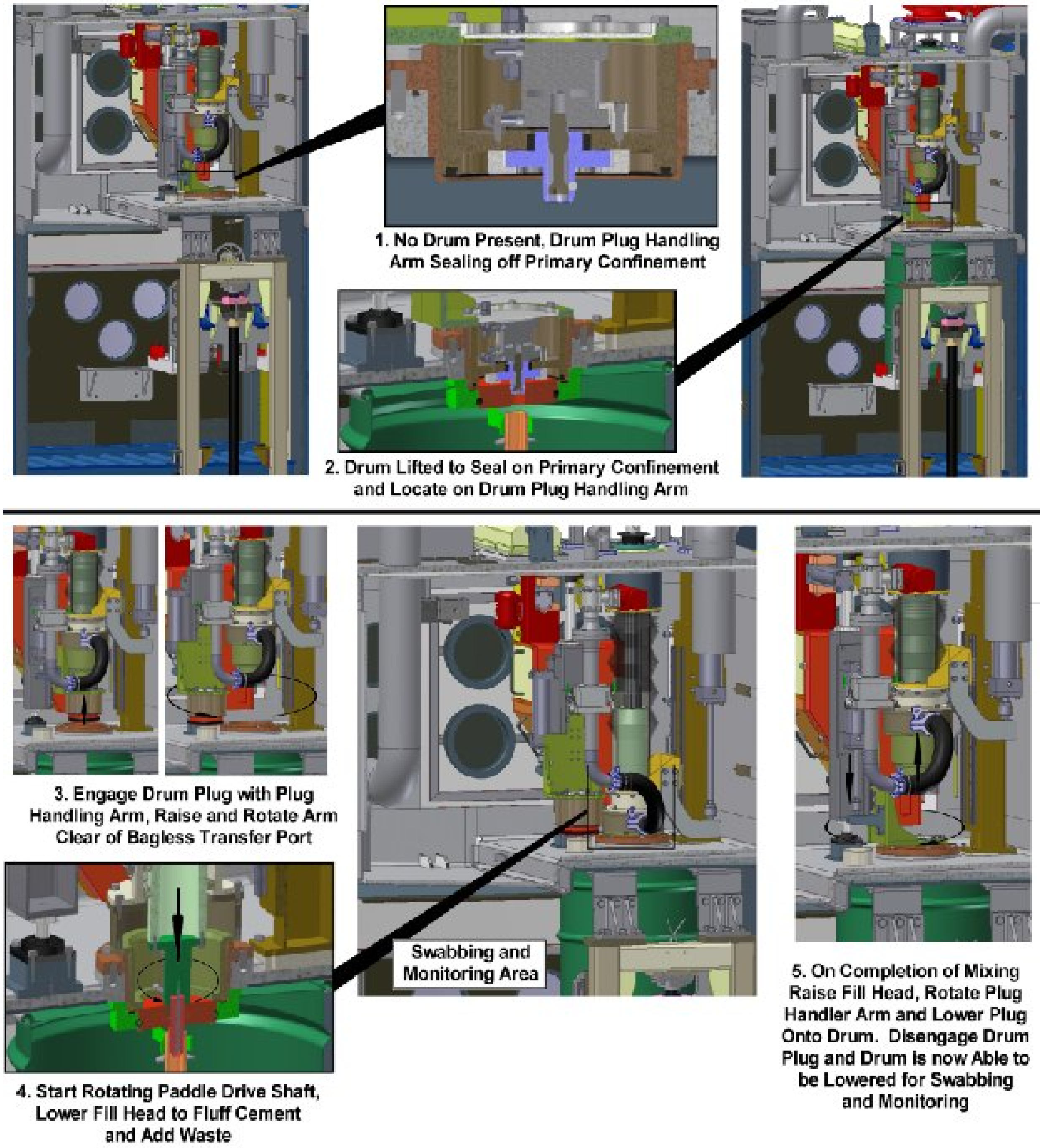
[2] Moss has been successfully used to dispose of a variety of nuclear wastes including Ion Exchange resins, sludges, evaporator bottoms and other tank wastes at Barseback, Sweden, Rossendorf, Germany and Borssele in the Netherlands.


1. No Drum Present, Drum Plug Handling Arm Sealing off Primary Confinement

2. Drum Lifted to Seal on Primary Confinement and Locate on Drum Plug Handling Arm

3. Engage Drum Plug with Plug Handling Arm, Raise and Rotate Arm Clear of Bagless Transfer Port

4. Start Rotating Paddle Drive Shaft, Lower Fill Head to Fluff Cement and Add Waste

5. On Completion of Mixing Raise Fill Head, Rotate Plug Handler Arm and Lower Plug Onto Drum. Disengage Drum Plug and Drum is now Able to be Lowered for Swabbing and Monitoring

Figure 4: Key CMS Bagless Transfer Operations

b. The mixing head drive shaft starts rotating at low speed and the head is lowered into engagement with the paddle and seals onto the drum, and the primary confinement floor. The cementitious material is then "fluffed" by the paddle rotation in accordance with parameters developed by the design team during full-size drum cementation tests.

c. Waste is then added and stirred into the cement under carefully controlled conditions to ensure homogeneity, minimize motor torque, and minimize dust carry-over into the off-gas system. This mixing process has a duration of approximately 30 minutes.

d. The fill head is raised and dwells for a few minutes, allowing any residual drips to fall into the drum.

e. The drum plug-handling arm is rotated and then lowered back into engagement with the drum, and the seal plug-locking pin is released. A drip tray on top of this arm ensures any final drips from the pour head are captured

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.

III. Secondary Confinement – Post-Mixing Operations

a. The drum elevator now lowers the drum back onto the conveyor and the elevator continues lowering until it is below the level of the conveyor rollers. Sealing between the primary and secondary confinements is affected at this stage by the plug handling arm seals, which mate to the bagless transfer port.

b. The drum is traversed on the secondary confinement conveyor to the swabbing and monitoring station where an operator, using gloveports, manually swabs the drum lid and monitors the swab with a contamination detection instrument to determine if any contamination is present. If necessary, any contamination will be manually removed by wipes and the drum lid resurveyed. It is at this station that the more secure DOT-7A, compliant drum outer lid, with integral Nucfil filter (to allow release of hydrogen due to radiolysis throughout drum storage), is manually fitted, fully enclosing the inner seal plug.

CMS RISK MITIGATION

During development of the CMS conceptual design the design team identified the key system risks as:

- Confinement of the Highly Active Wastes.
- The unconventional addition of liquid waste to cementitious materials within the waste drum[3].

As Energy*Solutions* had significant experience with confinement of similar wastes in various facilities it was determined that the first risk could be mitigated by careful designs that drew on that previous experience. However it was also determined that the process concerns inherent in the second risk could only be minimized by focused development work. Prior to submission of their proposal, Energy*Solutions* performed confirmatory trials to ensure the feasibility of the cementation mixing technique envisioned, and to develop a suitable paddle design. This work was performed sequentially at 2-gallon, 5-gallon and finally full-size 55-gallon scales. During these trials mixing parameters were developed, including torque, speed, duration and a suitable “D-paddle” mixing design, as illustrated in Figure 5, was evolved. The

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[3] 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.

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

Figure 5: Early D-paddle design developed for use on CMS (subsequently refined)

Building on the success of the pre-contract testing, full-size formal NQA-1 controlled, proof-of-concept testing was performed [2] using a prototypic test rig in accordance with client specifications, which included the following:

- Waste simulant and actual cement chemistry trials (original trials used Portland cement and water only) in accordance with client recipes.
- 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 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.

- Sectioning of drums to demonstrate that waste simulants were successfully incorporated into the cement matrix and that no excessive void spaces occurred and therefore only minimal free liquid could be present after grouting.
- 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 that required a variety of options to be trialed before a successful outcome could be achieved 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 a stall in the drive system and some elastic twisting of the rig before the motor cut-out. Other approaches caused overflowing of a small amount of waste simulant due to the combined volume of the waste, the cement and the trapped air within the cement exceeding the drum's capacity. However, after some optimization of the motor's Variable Frequency Drive settings and of the cement preparation, waste addition rate, and timing of the various process steps, a technique was developed which consistently produced conforming drums.

CMS DETAIL DESIGN

In addition to the key design features discussed previously, the following design challenges were also tackled and solved:

- Ensuring all drum positioning and mixing mechanisms are accommodated within the gloveboxes. See Figure 6 for the various positioning and mixing mechanisms within the primary and secondary confinements, which are described below.
    - Pneumatic cylinders within the glovebox elevate the fill head and rotate and elevate the drum plug handling arm. All supply and exhaust air from these cylinders pass through HEPA filtered nozzles on the glovebox wall.
    - Drum plug engagement and disengagement is via a ball lock system driven by a pancake cylinder on the drum plug handling arm.
    - Hoses attached to the fill head supply waste to the drum and ensure an air sweep is drawn through the drum ensuring displaced air is extracted into the facility vessel ventilation system.
    - Telescoping splines allow the fill head assembly to raise and lower relative to the electric gearmotor drive system, which sits on top of the glovebox assembly.
    - The drum is driven along the roller conveyor in the secondary confinement until it contacts an angled guide, which sits slightly higher than the top surface of the rollers.
    - The drum lift forks are raised by an electrically driven screw, causing the drum to centralize on the forks' angled guides.
- Ensuring all manual operations can be ergonomically performed.
    - During design reviews, both design team and client reviewers focused on the ergonomics of the gloveboxes. This resulted in some rearrangement of the gloveports and windows to ensure that routine operations will be more readily performed thus ensuring that operator radiation exposures are minimized and ALARA goals are achieved. A key confirmatory activity during Factory Acceptance Testing will be to ensure operators can perform the tasks in a timely manner without undue stress.

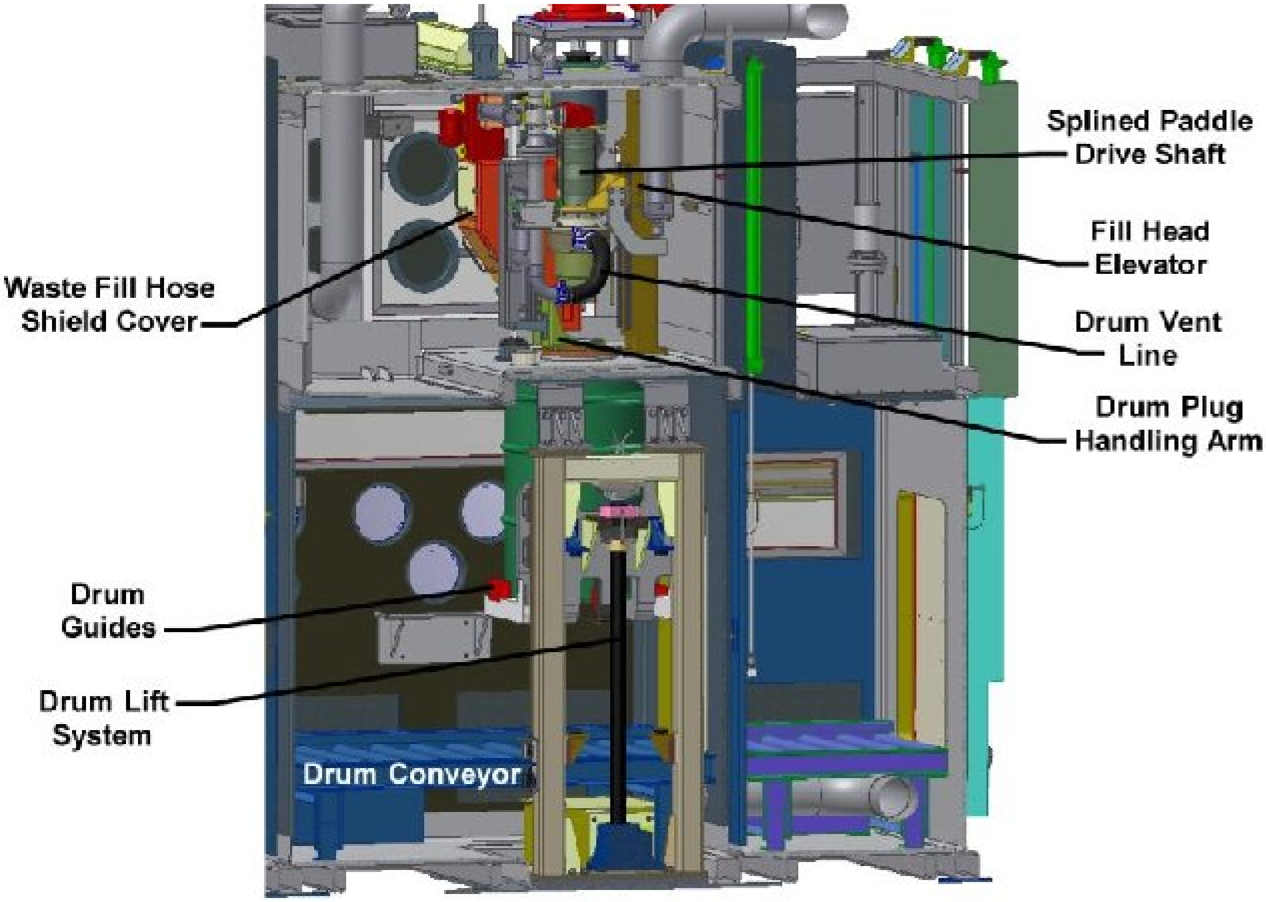

Figure 6: Arrangement of Mechanisms in Primary and Secondary Confinements

- Ensuring all equipment can be readily maintained.
  - All equipment requiring routine maintenance has been positioned either within the reach of gloveports or with removable panels to allow items to be removed should they fail during service. To facilitate this activity, the glovebox pairs are arranged with a common maintenance area between them, which can be "tented" to maintain confinement. In extreme cases, a waste drum can be removed through such a removable panel using a provided specialty drum handling beam and hoist.
- Balancing the conflicting needs of minimizing the amount of equipment within the gloveboxes versus minimizing the system design complexity and the number of penetrations through the confinement walls.
  - Each item penetrating the glovebox confinement was carefully considered to determine whether it could be readily maintained inside the glovebox or if the difficulty in maintaining it and the increased risk due to the addition of penetrations justified locating the equipment external to the glovebox. Accordingly, simple pneumatic drives within the enclosures were utilized for most of the light duty mechanisms, such as the seal plug

handling arm and fill head elevation, commercial electric drives were used within the gloveboxes for the drum handling equipment and an external gearmotor was utilized for the high torque mixing drive. Where possible, instrumentation is located external to the glovebox particularly for drum positioning, which utilizes non-contacting laser sensors viewing drums through the glovebox windows.

- Providing appropriate shielding for the HAW gloveboxes to protect operators from the Am241 gamma source present in the waste.
  - The shielding analysis performed determined the need for 0.75″ thick steel panels and 0.75″ thick lead glass windows in the secondary confinement to ensure annual operator dose goals are achieved.
  - A modular shielded box provides operator protection from the only major radiation source in the primary glovebox, the waste delivery hose.
- Meeting all client specifications including conformance to the American Glovebox Society Standards AGS G001, 1998 and AGS G006, 2005. A few of the many AGS requirements incorporated into the design include:
  - Guarding of equipment with moving parts.
  - Eliminating sharp edges or points to prevent glove damage.
  - Ensuring glovebox over and under pressure protection.
  - Filtering service penetrations on both sides of glovebox walls.
  - Mitigating the risk of explosions through ventilation and component design.
- Ensuring the client's nuclear safety basis is maintained by application of a quality assurance approach throughout the design and manufacture of the system.
  - Savannah River Nuclear Solutions determined that four subsystems need to be classified as Safety Significant to ensure achievement of the WSB nuclear safety bases. These systems were the primary confinement, the waste fill line, the primary confinement ventilation system and the drum ventilation system. The Energy*Solutions* design team consequently reviewed every component on the glovebox systems and classified them as either general service or safety significant. All safety significant items were then allocated safety function(s), critical characteristic(s) and acceptance criteria. Using these classifications the team have produced specifications for these items that will require that they are procured, inspected and tested in a manner which will ensure the maintenance of the client's safety basis.
- Optimizing equipment tolerances to ensure a reliable and yet cost-effective design.
  - The mechanical design group took great care in ensuring that the drum positioning system and bagless transfer system was compatible with commercially available drum tolerances. This required a clear understanding of equipment tolerance build-ups and utilization of drum handling methods to compensate for and minimize the impacts of commercial drum tolerances.
- Developing a robust design compatible with client facility ventilation system to ensure removal of the cementation reaction heat of hydration, to ensure ventilation zoning and to attain protective

inward air velocities in the event of glove breaches or any necessary removal of maintenance panels.

  - The client facility ventilation system provides all glovebox depressions. This is achieved by a conventional cascading system, which is set up utilizing lockable dampers. A nominal 175 cfm is drawn through an inlet pre-filter into the secondary confinement and in turn through a HEPA filter assembly into the primary confinement. Nominal flow rates of 6 cfm are also drawn through cartridge HEPA filters into each airlock, and in turn into the secondary confinement when either inner airlock door is open. The HEPA filter is sized to allow a flow of up to 1000 cfm necessary in such off normal conditions, as ensuring the removal of exothermic heat from a curing waste drum that cannot be exported. This flow rate is achieved by fully opening the in-series lockable dampers. Similarly, by opening of a lockable damper in the facility ventilation extract system a flow of up to 1000 cfm can be achieved through the apertures of removed maintenance panels to ensure that face velocities required by the AGS standards are achieved.

- Incorporation of features protecting operators from off-normal and accident events – i.e., fire suppression nozzles, sumps, leak detection instrumentation, etc.

  - A number of features have been added to the design to ensure protection of the operator during off-normal events. These include two diagonally opposite nozzles in each confinement and one in each airlock to allow operators to deploy a dry chemical fire suppression system in the event of a fire within the airlocks or gloveboxes.
  - Sumps are provided in each confinement and in the case of the primary confinement an air operated diaphragm pump and a volume hold up tank are fitted to allow recovery from a waste spillage and the controlled addition of this waste into a waste drum.

- Developing a robust, but moderately-priced, drum design capable of passing DOT-7A certification testing.

  - An important requirement is the ability to transport the HAW drums to the Waste Isolation Pilot Plant, and the LAW drums to the Nevada Test Site. It is, therefore, a statutory requirement that these drums be certified as DOT-7A packages for road transport to these storage locations. The team has carefully designed these drums to ensure that they can pass the stringent, drop, vibration, stacking, pressure, penetration, and spray certification tests scheduled for late Spring 2010.

- Designing the system to meet seismic and transport requirements.

  - The CMS uses a custom shell designed specifically for the process it contains and an integrated support structure designed to meet seismic and transport requirements. The custom shell design also allowed engineers to optimize ergonomic operation and maintenance activities to reduce the time required to perform operations; and therefore, to reduce personnel radiological exposure.

CONCLUSIONS

Development testing demonstrated that successful mixing is possible by the addition of liquid waste to cementitious materials, and that the reduction in the quantity of cement powders carried into the off-gas system is very significant when compared to experience on systems where conversely, powder is added to the drums after the waste. The CMS approach therefore simplifies the design of the gloveboxes by avoiding the need to include cement handling systems within the active area or the need for more complex cement capture systems such as baghouses with blow down features. Similarly, operator access and maintenance are both significantly simplified by the reduced amount of active equipment; and therefore, personnel radiation exposure shall be consequently reduced.

Development tests were also invaluable in providing data for the detail design of the CMS equipment, which would have been extremely difficult to obtain by any other means. Examples of this were the development and selection of mixing strategies which enabled the drive motor to be sized, drum clamping forces and other parameters such as duration of mixing, mixing speeds, waste addition rates, fluffing velocities, and durations, etc., to be proven empirically, and the resulting data confidently used in the subsequent detail design process.

The addition of tracer dye during mixing trials validated the effectiveness of the selected CMS bagless transfer type arrangement in the simultaneous confinement and grouting of simulated wastes within gloveboxes, and this will be further validated on the production equipment during the system Factory Acceptance Test.

By selective preliminary design followed by focused development testing, and the utilization of proven designs from the Energy*Solutions'* portfolio, the now complete detail design of the Cementation Mixing System is ideally placed to meet both its specification requirements and its performance goals.

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