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INTEC Tank Farm Facility Closure Mockup Test Report Project File No. 015722

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ABSTRACT

The tank farm at INTEC is being closed. To ensure that this is done in an efficient and safe manner, a proof of process is being done. The primary focus is evaluation of a mockup for washing the interior of the tanks. Tests, findings, and recommendations associated with the mockup are detailed.

SUMMARY

The Department of Energy's (DOE) weapons complex has been transitioning from production to environmental restoration (ER). In this process, the DOE has identified a large number of contaminated facilities which are surplus and need to be decommissioned. These activities must be done in a safe, timely, and cost-effective manner.

In this context, the tank farm at Idaho Nuclear Engineering Laboratories (INTEC) has been targeted for closure. This is a high-level waste project that will be closed in accordance with DOE Order 435.1 and the Resource Conservation and Recovery Act (RCRA) closure plan. To ensure that this is done in a safe, and efficient manner, a proof of process is now underway. A requirement in this project is protection of workers, the environment, and the public. Therefore, the main focus of this work is the safe and efficient removal of the contamination inside the tanks before closure. To this end, a mockup of the proposed equipment for cleaning the interior of the tank has been fabricated. This mockup includes a video camera assembly which was evaluated and found functional. Evaluation of the washing system identified opportunities for improvements which will require further evaluation. This report details tests, findings, and recommendations from these initial evaluations.

Tests preformed and their recommendations include:

Video camera equipment and systems testing demonstrated the effectiveness of the remote camera operation, camera mounted lights, and an air lance for keeping the lens dry during tank closure procedures. All testing was successful and positioning of the assembly in the actual tank to minimize spray will be accomplished.

Tank washing and mixing of surrogate solids determined the efficiency of the washing system as well as the functional performance of the support systems. The optimum wash ball nozzle size was selected. The need for directional spray nozzles to wash the floor was determined and tested. Efforts to minimize the quantity of wash water will be performed during actual tank washing.

Steam jet testing determined the performance of surrogate solids transfer from the tank and established improved coordination with the washing and mixing systems. The existing steam jets will be an effective method to remove liquids and solids suspended in the liquids for the actual tank washing.

Surrogate solids testing provided a conservative example of the solids to be encountered in the actual tanks. The surrogates were used in all washing and pumping mockups. Tests from the actual tanks provide information that the solids in them will be removed at least as easily as the surrogates were in the mockups.

Slurry Pipe Flow testing provided the opportunity to see removed, pumped solids moving through clear piping with bends and simulated valves. No blocking in the discharge lines occurred.

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FY 2000 Tank Farm Closure Mockup Outline

1. INTRODUCTION

This project is the concept design phase for the closure of the INTEC Tank Farm Facility. It provides the initial stages for proof of process for the tank closure equipment. Proof of process is accomplished by using mockup testing. The primary focus of the mockups is the interior washing of the tank and the associated tank closure equipment. The equipment was tested under controlled conditions similar to the actual Tank Farm Facility (TFF). Surrogate solids with physical characteristics similar to the existing tank solids were utilized in the mockup. The washing mockup tested the following:

- Video camera system
- Wash-ball system
- Controlled directional nozzles
- Steam-jet pumping system.

A full-scale half tank was constructed for testing tank farm closure procedures and equipment. The half tank constructed was an epoxy coated plywood tank with three clear Lexan® windows in the walls and a 16 ft by 16 ft section of stainless steel tank wall. Cooling coils were located on the floor to simulate the physical coils in the actual tanks. Stainless-steel coils were located on the stainless-steel wall section as well. The tank was partially filled with water and functional testing was performed on installed equipment prior to adding the surrogate solids. A second remote video camera was located below the floor of the constructed tank. This mobile video camera was positioned at one of two clear Lexan® windows in the tank floor. Surrogate solids were added to the constructed half tank after mounting the tank closure equipment. The surrogate solids were placed in the tank at an approximate initial depth of 8 in. A separate holding tank was filled with water and was the source of water for the wash ball. The water and solids discharged from the steam jet were also piped to this holding tank to allow the solids to settle out. Qualitative and quantitative data was recorded from the testing, including video footage and pictures from several cameras and various measurements. The summary for the tank closure equipment testing is provided in this report and the summarized results are given with reference to more complete test results as necessary. Where applicable, the Lessons Learned are presented.

2. TEST PROCEDURES

2.1 Video camera system, CA-ZOOM PTZ-4.2

During actual tank closure in the TFF a video camera system will be lowered through one of the tank riser nearest the center of the tank. Within this same tank riser the wash ball will also be located. The video camera system will be positioned above the wash ball and have a spray deflector to prevent direct impingement on the camera. The camera is controlled from the CA-ZOOM camera control unit (CCU) pendant module that will be located in a control trailer outside of the TFF fence. Testing in the mockup focused on the camera performance in the following areas:

- Pan movement of +/- 175 degrees
- Tilt movement of + 129 degrees to–105 degrees from vertical orientation
- Zoom range of 18:1 optical X 4:1 digital for a total of 72:1 zoom capability
- Manual and automatic focus modes
- Light intensity for both lamps, including off/on and turbo functions
- Manual and automatic brightness function
- Manual and electronic shutter speed control function
- Camera system “Shadow Brite” function
- Camera housing pressurized to 10 psi with a “dry” inert gas (preferably nitrogen)
- Water tight integrity of the camera/light housing during tank washing operations in the tank mockup. No visible water, moisture or humidity indications (fogging) on the inside of the lenses should be visible after extended operation in the mockup tank structure during washing operations
- Visual clarity on the monitor and recording capability.
- Clarity after full magnification using the digital and optical zoom.
- Lens protection (air lance) from spray from the wash ball and condensation and removal of any condensation or water from the lens so the picture quality is not significantly degraded and interferes with the qualitative assessment of tank closure operations. (The air lance system is an after market item developed and installed by the INEEL Remote Systems Applications Group for use on this camera system).

The remote camera housing is constructed of stainless steel. The monitor and controls are connected via a cable system. An additional air lance system was installed on the camera over the lens. The air lance is a stainless-steel ring around the camera viewing window that forces clean, dry air over the window to prevent water or particles from accumulating and obscuring the picture quality. The camera was used extensively during the mockup testing and recorded footage of the wash ball and steam jet. All the remote camera systems features were operated and results are noted in the following sections.

2.2 Wash Ball System

The wash ball is a stainless steel rotating two-nozzle washing system. These types of washing systems are used in the petroleum and shipping industries. The wash ball will be lowered into the tank through one of the center most tank risers along with the video camera. Various nozzle sizes were preliminarily tested prior to adding the surrogate solids. Nozzle bore sizes range from 7 mm to 12 mm.

The location of the wash ball is fixed in the actual tank. Mockup testing focused on the following:

- The behavior of the water spray/stream from the various sized nozzles at maximum distances
- The water consumption rate and the water pressure supplied to the wash ball
- The cleaning ability of the wash ball on the solids on the wall
- The agitation of solids on the tank floor with varying levels of water in the tank and covering the solids
- The ability of the wash ball to mix and suspend the solids throughout the tank for removal
- The coverage of the spray stream from the wash ball over the entire tank interior surface
- The cycle time to wash the entire half tank interior surface once
- The effectiveness of agitation and suspension of the solids for the wash ball spray pattern.

A mobile video camera below the floor of the mockup was intended to record potential disruption from the wash ball or movement of solids over the clear Lexan® windows in the floor. This mobile video camera was monitored during the washing.

2.3 Controlled Directional Nozzles

During testing the actual spray coverage from the wash ball was limited by a light-gauge steel housing. This housing prevented the spray from the wash ball from hitting the two opposite corners of the tank. The solids present in these corners represent the worst case condition of accumulated solids. The actual directional nozzle location within the TFF tanks will be from the north and south of the two perimeter tank risers.

Testing the directional nozzles will include the following:

- The pressure and flow rate through the nozzle
- The most efficient targeting of the spray nozzle onto the solids to move them to the steam jet
- Determining a sequence of wash ball and directional nozzle operation for the most efficient removal of solids.

2.4 Steam Jet

The steam jet pump used during testing has similar performance characteristics to the steam jets located within the TFF tanks. Each TFF tank has two steam jets. One jet is located in each of the center most tank risers. Tanks WM-182 and WM-183 will have the center most steam jet removed in order to place the wash ball and camera into the tank. The remaining steam jet will remain in the tank but will be modified at the top of the tank riser to allow height adjustment. The steam jet used for testing in the mockup was located similar to the actual TFF tanks and was height adjustable. A steam generator will supply the steam necessary for the steam jet and flow meters will be placed on the discharge piping.

Steam jet testing will include the following:

- Recorded flow out of the tank from the steam jet
- Percent of solids removed from the tank
- Steam flow rate in lbs/hr
- Most effective height of the steam jet for solids removal
- Recorded temperature difference between the steam jet discharge liquid and the liquid in the mockup tank
- Pumping performance of the steam jet with varying amounts of water and solids concentrations
- Restarting the steam jet after extended operation to determine worst case conditions for failure
- Steam pressure, PSIG.

2.5 Surrogate Solids

Selection of a simulated solid surrogate to mimic the physical characteristics of sludge located in tank WM-182 and tank WM-183 within the INTEC Tank Farm Facility (TFF) has been performed. In order to manage the TFF solids, it was desired to mimic the solids settling rate, density, viscosity characteristics, etc. for use in a TFF closure mockup. The mockup utilized water dispensed at high pressure from a wash ball to suspend or fluidize solid particles for removal via the steam jet to another tank.

The wash and pump mockup used a wash-ball system that scoured the sides of the tank walls with water, agitated the solids present in the tank heel, and diluted the liquid present in the tank heel. The wash-ball system consisted of two water jets that discharged in opposite directions. These jets rotated vertically, while the entire wash-ball rotated horizontally. Primary objectives of this operation were to remove solid waste adhered to the walls of the tank, dilute the liquid heel to a pH above 2, suspend the solids for removal, and leave approximately one inch of solids in the bottom of the tank prior to grouting. A steam jet system was operated in conjunction with the wash ball to remove the solid/liquid heel.

In this mockup, the TFF tank to be cleaned was represented by a full-scale, half-tank with cooling coils. This half-tank was approximately 50 ft in diameter with 20 ft in height walls. The wash-ball and steam jet were placed in locations consistent with the TFF tanks.

When the system was operating, steam (1,000 lb/hr) flowed through the steam jet and removed the tank heel to a settling basin. As the solids from the steam jet discharge settled within the basin, water was drawn from the settling basin to the wash-ball in the half-tank mockup. An ultrasonic flow meter and pressure gauge monitored the flow through the steam jet and wash-ball respectively. Valves were manually turned to control the flow through these lines.

Heel samples from WM-182 and WM-183 had been taken with the Light Duty Utility Arm (LDUA) along with considerable TFF video footage. These heels are sludge consisting of solid particles with liquid occupying interstitial spaces between these particles. The samples were taken to the Remote Ananlysis Laboratory (RAL) for analysis. Based upon RAL analysis data, LDUA video footage, material, preparation, and expense considerations, and the need for an environmentally inert surrogate, a suitable surrogate was developed as detailed in EDF 15722-041 “Surrogate Sludge for Tank Farm Closure Mockups” (see Appendix A). It was determined that kaolin clay in water (pigmented with iron oxide) and flocculated with aluminum sulfate (alum) provides an effective surrogate.

2.5.1 Development of Surrogate Sludge

Development of a surrogate sludge and its use in a TFF tank closure mockup was desired for a variety of reasons. The surrogate sludge**:**

- Provides a means to measure the effectiveness of tank washing operations on removing solids adhered to tank walls and solids to be suspended for removal via the steam inductor. This effectiveness includes an estimation of the wash-ball operating pressure, nozzle quantity, and bore size, and an estimation of the amount of water required per amount of sludge removed

- Provides a means to measure potential plugging problems from respective solids concentrations in piping downstream from the eductor

- Provides a means to measure the amount of sludge displaced from additions of grout of varying slump rates

- Provides a means to measure how the sludge is encapsulated or entrained within the grout

- Provides a basis for estimating sludge mass remaining in the tanks after wash-ball and grouting operations to base radiological and hazardous source term calculations in support of TFF conceptual design closure.

2.5.2 Surrogate Solid Benefits

Below is a summary list of the chosen surrogate benefits*:*

- The surrogate solids settling rate compares closely to the settling rate and particle size distribution of the WM-183 actual sludge

- No acidic or basic solution required as part of the process make-up (other than the coagulating agent Aluminum Sulfate which has mild acidic properties)

- Ingredient materials are inexpensive
- Materials are safe and environmentally friendly to use
- Generation of the surrogate sludge and disposal of the surrogate sludge will not be regulated as hazardous waste under the Resource Conservation & Recovery Act (RCRA)
- All materials can be mixed together in two steps. The kaolin, water, and iron oxide are to be mixed in the first step followed by the alum
- Particles in the surrogate exhibit a particle size distribution similar to that of Tanks WM-182 and WM-183 - the bounding tank for the simulated solids mockup effort
- The material exhibits a yield stress (based on visual observations) that matches LDUA video footage visuals of WM-182 and WM-183 sampling operations. There is an observed oscillation of the surrounding surrogate sludge from the point of disturbance similar to that of the WM-182 sludge. There is also a similar cracking appearance around and area of sludge removal or relocation. There is a relative rigidity of surrounding material directly near an area of sludge removal or relocation often leaving a *clumpy* appearance of the sludge
- The mixed sample slurry and then settled surrogate sludge results in two distinct phases for the sludge system as does the observed WM-182 sample in RAL, that is, a sludge layer with a clear supernate above
- The mixture exhibits two settling characteristics: (a) Upon complete disturbance of the sludge, the particles are of such high density (close proximity to one another) that a settling zone develops as the particles move in a defined horizontal layer enmasse, as a moving filter capturing all particles via gravity settling. In this type of settling, one observes three distinct areas within a settling vessel - a clear supernate, a settling zone of particles, and the settled zone. (b) Upon partial disturbance of the sludge, the particles *billow* up from the sludge surface and then randomly settle until the supernate is clear. There is no distinct horizontal zone settling in this case
- Material is easily colored with iron oxide of similar particle size. The color stays with the surrogate sludge (solids). The supernate remains clear. Red iron oxide is chosen over black, browns, and yellows for it has the highest chroma value and can be seen the easiest.

3. SUBCONTRACTOR CONSTRUCTION DATA

3.1 Introduction

In order to do the mockup testing, a full-scale tank, with steam jet and spray nozzle needed to be constructed. Portage Environmental, Inc. was subcontracted to construct the partial, full-scale tank and associated tank-closure systems to mockup a pillar-and- panel style tank for the INTEC Tank Farm. For their Construction Report see Appendix D. Construction and testing activities took place in a leased facility located at 1293 East 65th North, Idaho Falls, ID, which provided approximately 7,000 ft^2 of interior floor space and additional outdoor area. mockup construction began the last week of March 2000 and demolition of the interior tank and systems was completed the first week of December 2000.

The mockup tank was a full scale, one-half diameter tank similar in size to a TFF tank. The mockup tank was approximately 25 ft-0 in. radius and approximately 16 ft-0 in. in height. The mockup tank was constructed of mostly plywood surfaces with one area lined with stainless steel plates. Simulated cooling coils were added to the walls and on the floor. The walls and floor were coated with epoxy paint to make it essentially watertight. The walls and floor had polycarbonate viewing windows.

3.2 Construction

Construction was performed in accordance with A-E Construction Specification SPC-244 and drawings with Portage personnel providing construction and safety oversight. A team of engineers was assigned approval authority that ensured adequate coverage for all contractor/subcontractor work schedules. Contractor quality assurance inspectors provided scheduled and random inspections of materials and workmanship during mockup construction. mockup tank construction started on March 22, 2000, with the installation of the structural steel members and was completed for initial test fill on August 11, 2000.

4. RESULTS

4.1 Video Camera System, CA-ZOOM PTZ-4.2

The actual video camera that was purchased for use in the Tank Farm Facility during washing and grouting was used in this mockup. The model purchased was an Everest/ VIT CA-Zoom PTZ-4.2 (see Figure 1). Video recorders were operating during most of the testing. The camera assembly includes two lights that can be controlled remotely. Each light is 35W at 12V. One light is a 30 degree flood and one is a 10 degree spot unit. An air lance was designed and installed over the camera lens to remove any moisture that gets on the lens.

Through all of the mockup testing the camera functioned well and no equipment failures occurred, including pan, zoom, and manual and automatic focus modes. Remote control operation of the camera and its lights from the CCU was relatively easy to learn at the mockup. The lights also functioned well during the mockup testing. Successful tests included light intensity, manual and automatic brightness, and *Shadow Brite* function. Mockup testing of the air lance successfully cleaned the camera well when it was splashed on by wash water. The camera housing was pressurized to 10 psi. The water tight integrity of the camera/light housing during tank washing operations was verified. No visible water, moisture or humidity indications (fogging) occurred on the inside of the lenses. Visual clarity on the monitor was always maintained. Recording capability, clarity after full magnification using the digital and optical zoom, was also verified and was considered of high quality.

Figure 1. Video camera system, CA-ZOOM PTZ-4.2.

4.2 Wash Ball System

The performance of the wash ball to remove solids from the walls and cooling coils and to agitate and suspend the solids was the primary concern (see Figure 2). In conjunction with the steam jet pump, the effective removal of solids was demonstrated. Approximately eight hours of washing with the wash ball and pumping with the steam jet removed 85% of the solids. After the initial eight hours approximately 1 in. of solids remained on the bottom of the tank.

The wash ball did a good job of washing the walls of the tank at the mockup. The built-in, automatic pattern of the wash ball did over spray the roof and did not move the water and solids on the floor well except in the area of the jet. The automatic spray of the wash ball pushed the solids on the floor toward the outside walls. This made it harder for the last few inches of solids across the tank floor to be removed by the steam jet. There appeared to be a wave action from the wash ball spray pattern onto the floor that caused liquid movement toward the walls. The cooling coils on the floor of the mockup added to this complication by making it harder for solids to move back toward the center of the tank. This situation should be very similar to what will happen inside of the actual tank. Although the wash ball removed approximately 85% of the solids on the floor, the remaining solids were concentrated near the walls. Effectively, the water consumption to remove the remaining 15% of the solids increases dramatically, necessitating the use of directional nozzles.

Figure 2. Wash ball with 2 head nozzle attached, 4 head nozzle shown in foreground.

4.3 Controlled Directional Nozzles

One of the primary observations from running the wash ball was its effect on the solids on the floor of the tank. The wash ball action caused waves on the floor to move toward the outer walls of the tank. This in turn caused the solids layer to remain thicker further out from the center of the tank. The cooling coils on the bottom of the tank also inhibited the water and solids from moving or settling back toward the center of the tank.

This inability of the wash ball to move all of the solids toward the center of the tank for removal by the steam jet, verified that directional nozzles will be required. A directional nozzle is one that can be pointed directly at trouble areas needing solids to be moved. The use of directional was tested at the mockup. The nozzles were directed to each corner for approximately one half of an hour. The result was an overall reduction of tank solids, the remaining solids was approximately ½ in. and it was determined that over 90% of the solids had been removed at this time.

4.4 Steam Jet

The steam jet performed well in removing the water and solids from the mockup tank. The height-adjustment capability allowed efficient removal of solids during tank washing. Overall no problems occurred, the only concern is lowering the steam jet to close to the floor and stopping flow. The suction from the pump pulled the jet to the floor if it was located lower than one-fourth inch from the tank bottom. This seemed to be primarily due to the design of the jet support system in the mockup and may no be an issue in the actual tank. However, if a new jet is installed in the actual tanks, the design will consider spacer tabs on the bottom of the new jet to avoid locking onto the bottom of the tank. Recommendations to ensure reliable performance of the steam are given in Section 5.

4.5 Surrogate Solids

4.5.1 Wash and Pump Mockup

Surrogate ingredients were ordered (see Appendix B) and delivered to Valley Ready-Mix of Idaho Falls. Valley Ready-Mix prepared the surrogate solids by mixing surrogate ingredients in cement trucks. Specified quantities and mixing sequence instructions were delineated in a detailed procedure (see Appendix C). Bechtel BWXT Idaho employee oversight ensured adherence to the procedure. Mixed surrogate solid slurry was delivered via cement truck chutes directly into the mockup half tank where the solids settled to form the desired sludge and supernate layers. Approximately 7.5 in. of sludge (4,590 gal.) of sludge was present in the tank when the system was started. Sludge was also placed on the half-tank walls to simulate the solids adhered to the TFF tank walls.

EDF-15722-048 “FY-2000 Tank Farm Closure Mockup Test Report” (see Appendix D) details the performance of removing the surrogate solids from the half-tank mockup and correlates an estimate of the required amount of wash water needed for the actual washing of the INTEC TFF tanks.

Throughout the duration of the mockup, the desired properties of the simulated solids surrogate held up well. Aging of the simulated solids (flocculated kaolin system) appeared to increase the settling rate as addressed in EDF 15722-041 “Surrogate Sludge for Tank Farm Closure Mockups”. This provided a conservative basis for estimating the amount of wash water needed as faster settling particles require more water at a given wash-ball operating pressure and nozzle size. Due largely from cool to cold temperatures during mockup activities, biological growth within the surrogate solids was not a problem and no biocide additive was required. The desired yield stress properties and density of the sludge remained the same for the duration of the mockup.

The results of the mockup demonstrated that the majority of the solids in the TFF tanks (floor and walls) can be effectively removed with the combination of a wash-ball system to agitate the solids and a steam jet system to remove the agitated mixture from the tank. However, the effectiveness of this system was decreased significantly as the solids were removed and the bottom of the tank was exposed. At this point, solids seemed to accumulate near the tank wall/bottom seam and removing these larger/heavier solids became more difficult. Alleviating this problem involved placing two directional nozzles through side risers near the tank wall. These nozzles were used to disperse the solids from the accumulation areas where they were removed by the steam jet.

It is estimated that 62,000 gal of wash water was needed to reduce the sludge height in a full-sized TFF tank from 7.5 in. to 1.0 in. (87% by volume removed). This mockup was considered to be the worst case tank. An estimate of the entire TFF gives an average of 3 in. of sludge per tank. If all tanks had 7.5 in. of sludge, closing the entire tank farm would require an additional 500,000 gal of wash water through the wash-ball system. Best professional judgement indicates that the directional nozzles would require an additional 50% of this volume (250,000 gal). Because the actual average is only 3 in. of sludge, less than one half this quantity of water may be necessary. For the tank-farm closure project, the estimated volume volume requirement for the tank farm/evaporator system is only 350,000 *gallons* or less.

Please note that the directional nozzle system brought the sludge height from 0.89 in. to below .06 (1/16) in. Therefore, the entire wash-ball/directional-nozzle system removed approximately 99.2% (by volume) of the solid material in the mockup tank. This shows that the directional-nozzle system is quite effective in removing the accumulated solids.

During the wash-ball test, an average solids loading through the steam jet was calculated to be 145 g/L when the solids height changed from 7.5 in. to 2.1 in. The steam jet operated for approximately 337 minutes during this period. Therefore, this mockup demonstrates that the steam jet can be used to transfer surrogate solids at much higher solids concentrations than previously thought.

4.6 Slurry Pipe Flow Mockup

In addition to the Wash and Pump Mockup, a Slurry Pipe Flow Mockup was performed. (see Figures 3 and 4). The purpose of this mockup was*:*

- To calibrate the ultrasonic flow meter such that the measurements taken during high solids concentration flows are reasonably accurate
- To demonstrate that the steam jet system can transfer a high solids loading flow without plugging a transfer line
- To simulate the transfer line configuration, including distance, elevation changes and restrictions created by valves.

The results from this mockup are significant. A conversion factor for changing the ultrasonic flow meter readings to volumetric flow rates with significant solids present in the flow is calculated to be 9.3 gpm/meter reading. Previous reports have created an upper limit of 30 g/L solids concentration flows through a TFF steam jet and piping systems. In order to use the wash-ball retrieval system, transfer of slurries with solids concentrations much greater than 30 g/L is required. This mockup shows that a steam jet/piping system similar to the INTEC system transfers surrogate slurries as high as 165 g/L.

Figure 3. Slurry Pipe Configuration

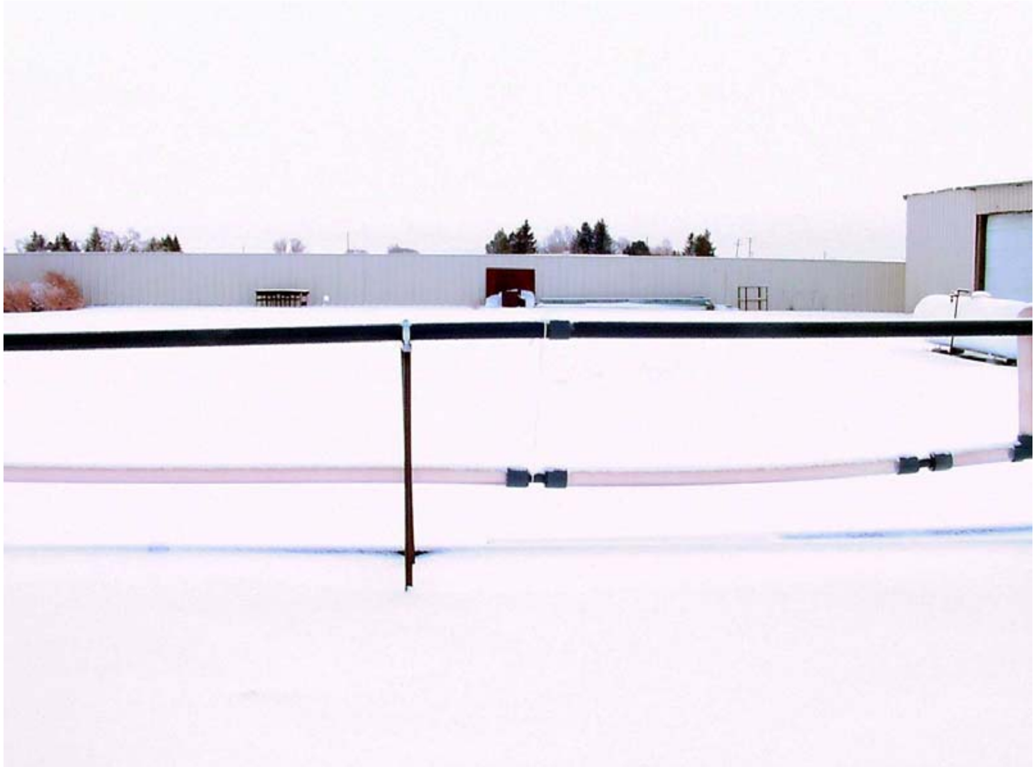

Figure 4. Slurry Pipe Flow Mockup Clear Piping

The mockup will simulate impractical conditions by transferring high solids loading through the transfer piping with the steam jet. The high solids loading is achieved by constructing a large *box* around the steam jet and filling it with surrogate solids. Water is decanted from the box as the solids fall out of suspension, increasing the overall density and reducing the water content of the transferred slurry. The solids concentration achieved for the mockup is approximately 5 ½ times greater than the upper limit allowed for transfer through the TFF steam jet and piping systems.

The routing of the piping system is taken from as built routing of the transfer line in the TFF from tank WM-182 to the designated holding tank WM-187. The route from WM-182 is through several valve boxes, including valves and multiple elbows. There are elevation changes in the TFF transfer line and these along with the elbows and valves are simulated in the mockup. The valves are simulated by using small diameter sections of piping and are placed at the approximate locations similar to that of the actual TFF transfer line. A sketch was generated that shows the plan and elevation details of the transfer line between WM-182 and WM-187, the sketch is titled “Slurry Pipe Mockup Drawing” and is located in Appendix E. This drawing was used to guide the layout and location of elbows, elevation changes and simulated valves. Clear pipe sections are used to allow observation of the flow and to identify and potential problems during the transfer.

5. LESSONS LEARNED

5.1 Video Camera System (CA-ZOOM PTZ-IV)

The actual video camera that was purchased for use in the Tank-Farm Facility during washing and grouting was used in this mockup. The video camera is a CA-ZOOM PTZ-4.2 supplied by Everest / VIT. It is controlled from the CA ZOOM camera control unit (CCU) pendant module. An operator controls the camera remotely while watching a monitor. Two Video recorders were also installed in the rack mount control console along with the CA ZOOM control module. The video recorders can also be run constantly. The camera has two lights mounted on it that can also be controlled separately and remotely. An air lance was designed and installed with the camera to remove any moisture that gets on the lens viewing window. Through all of the mockup testing the camera functioned well and as expected.

5.1.1 Remote Operation

Remote control operation of the camera and its lights from the CCU was relatively easy to learn at the mockup (see Figure 5). The operator should practice using the remote controls prior to the actual operations inside the tanks. With a small amount of training and practice the remote operators should have no problems viewing and recording all the closure activities inside the tanks.

Figure 5. Video camera system remote operation and video recording system.

5.1.2 Lights

The lights functioned as well as expected during the mockups. The remote operator should learn to operate the lights during training and practice runs inside of the tank. Viewing the video monitor provides the best approach to understanding the best use of the lighting intensity system for optimal video recording purposes.

5.1.3 Air Lance

Mockup testing of the air lance successfully cleaned the camera lens well when it was splashed on. Viewing with the camera lights only (with the facility lights off) created some problems due to the reflective sparkling effect of water droplets in the air in front of the camera head. However, adequate viewing was achieved through positioning, as described below. The air lance was operated at 10 psi for removing moisture from the camera lens viewing window (see Figure 6).

Figure 6. Video camera, showing air lance ring and the two factory mounted lights.

5.1.4 Positioning

The location of the camera relative to the spray ball should be optimized to reduce spray not only on the lens but also blocking the lens. For this reason a spray deflector should be designed that would minimize spray toward the lens viewing window of the camera.

5.2 Wash Ball System

5.2.1 Wash ball nozzle selection

Several sizes of nozzles were tested including 10 mm nozzles. Based upon washing performance the 10 mm nozzle is recommended. Flow rate is dependent on the pressure of the water supplied to the wash ball. The recommended pressure range is 80 to 100 psi. This will produce a flow rate from 75 gpm to 88 gpm, based upon manufacturers data.

The nozzles were drilled out and reamed to the exact size along the entire length of the bore of the nozzle. This improved the discharged stream stability resulting in better washing performance.

The two critical areas of concern were the washing performance and the rate of water used during washing (see Figure 7). The washing performance was based upon visual inspection of the water stream impacting the liquid and solids on the tank bottom. The stream from the 9 mm nozzle diffused into a spray and was not as effective for washing as the larger 10 mm diameter nozzles. However, the larger the diameter of nozzle, the higher the water flow rate. Efficient water consumption for tank closure is important. During testing 11 mm and 12 mm nozzles were used and provided good washing performance. The large nozzles did not provide better performance over the 10 mm nozzles and will not be used as they use a higher water flow rate.

The two nozzle configuration for the wash ball is recommended over the four nozzle configuration. Two factors were considered in the recommendation. First, the four nozzle wash ball used more water, as expected. Second, the four nozzle wash ball has a wider cross section overall. This additional width would make insertion and removal of the wash ball into and from the tank riser a more difficult task.

Figure 7. Mockup tank washing spray from wash ball.

5.2.2 Wash Ball Flow Ring Assembly

The existing wash ball has a flow ring that has angled vanes. This flow ring drives the rotation speed of the wash ball, both the horizontal rotation and the nozzle rotation as a result of the gear drive system. The rotational speed is related to the rate of water flowing through the wash ball and the configuration of the flow ring vanes. The current wash ball rotation rate at the preferred water flow is too high. Replacing the existing flow ring with another flow ring with straight vanes will slow the rotation of the wash ball. This will allow the impact from the stream to have a longer residence time per location, improving the washing performance. This straight flow ring was installed in the wash ball for some of the mockup testing (see Figure 8).

Figure 8. Wash ball, four-head nozzle and two head nozzle cross section comparison.

5.2.3 Wash Ball Areas to Improve

The wash ball did a good job of washing the walls of the tank at the mockup (see Figure 9). The built-in (automatic) pattern of the wash ball did over spray the roof and did not move all the solids on the floor. Approximately 85% of the solids were removed with the wash ball. To use the wash ball to remove the remainder of the solids would increase the water consumption significantly.

Figure 9. Wash ball mounted in mockup structure prior to washing.

5.2.3.1 The automatic spray of the wash ball pushed the solids on the floor toward the outside walls. This made it harder for the last few inches of solids to be removed by the steam jet. There appeared to be a wave action from the automatic spray pattern onto the floor that caused liquid movement toward the walls.

5.2.3.2 The cooling coils on the floor of the mockup added to this complication by making it harder for solids to move back toward the center of the tank. This should be very similar to what will happen inside of the actual tank (see Figure 10).

5.2.3.3 Much of the water that was sprayed on the roof is not required for washing. An attempt to minimize water usage at the roof would be desirable. Spray ball usage and directional nozzle usage will be balanced to optimize the water usage.

5.2.3.4 It is the design team's belief from operating the mockup that directional spray nozzles are required to push solids on the floor toward the steam jet for removal.

Figure 10. Mockup tank floor before directional spray wash.

5.3 Controlled Directional Nozzles

One of the primary observations from running the wash ball was its effect on the solids on the floor of the tank. The wash ball action caused waves on the floor to move toward the outer walls of the tank. This in turn caused the solids to remain thicker further out from the center of the tank. The cooling coils on the bottom of the tank also inhibited the water and solids from moving or settling back toward the center of the tank.

This inability of the wash ball to move all of the solids toward the center of the tank for removal by the steam jet, drove the decision that directional nozzles will be required. A directional nozzle is one that can be pointed directly at an area needing solids to be moved. This was tested at the mockup. A directional nozzle was placed on a hose and sprayed directly at areas on the floor of thicker solids buildup. The directional spray easily moved the solids toward the steam jet for removal. This directional nozzle could also be used if a spot on the wall was not washed away using the spray ball.

5.3.1 A design is underway that is simple, functional, and will need to be tested

At the time of this report a directional nozzle design is underway under the Title Design portion of the INTEC Tank Farm Closure Project. In the actual tank, the directional nozzle would be lowered down a riser on a mast. The video camera and its lights would also be inside of the tank. Using the camera, an operator at a monitor would direct the area of spray of the directional nozzle.

5.3.2 Optimizing the quantity of wash ball verses directional nozzle usage will be required

In order to get the maximum cleaning possible using the least amount of water, the amount of time the spray ball runs and the amount of time the directional nozzle is run should be optimized. It is important to run the spray ball to saturate the walls of the tank and wash as much of the area automatically as is practicable. The directional spray will be a remotely operated activity and its operation will be labor intensive. The amount of directional spray can be minimized using sufficient spray ball operation.

5.3.3 Directional nozzle is required to directly spray solids to move them toward the steam jet for removal

Utilization of directional nozzles in conjunction with the wash ball will optimize washing and solids removal. Although the mockup established a basic sequence, wash ball followed by directional nozzle usage, further testing may reduce the amount of water usage required for cleaning. Directional nozzles are effective for pinpoint washing efforts on troubled areas in the tank and are necessary to effectively remove the solids that cannot be efficiently removed by the wash ball.

5.4 Steam Jet

The ability to raise and lower the steam allows the most efficient removal of tank solids. The steam jet should have the capability to lower within 0.25 in. to 0.375 in. of the tank bottom. Provisions are required to maintain this distance to the bottom of the tank. A physical depth limiting device attached to the steam jet is recommended to keep the jet from bottoming out on the tank floor (see Figure 11).

Figure 11. Steam jet mounted in Mockup structure prior to washing.

Ideally the steam jet should remove an amount of liquid equal to the amount of water added by the spray ball or directional nozzles. This would allow almost continuous operation without pauses to allow for the jet to catch up with the spray ball for example. Balancing the water supplied from the wash ball with the water and solids removed by the steam jet was difficult. This was due to the wash ball supplying water at a higher rate than the steam jet could remove from the tank. The water supplied to the wash ball was fixed due to the required pressure for effective washing. This required stopping the wash ball periodically to allow the steam jet to remove adequate amounts of water and solids. The reason it is important to maintain a balance between the wash ball supply and the steam jet discharge is to allow the effective agitation of the solids at the tank bottom. When water level becomes too high, the stream from the wash ball does not agitate as effectively the solids present at the bottom of the tank. Stopping the wash ball allows the uninterrupted settling of solids, decreasing concentration of solids suspended in the liquid and the overall solids removal from the tank. The most efficient washing process would be to allow the wash ball to run continuously. This would require a steam jet with matching capacity or an adjustable range to meet the capacity of the wash ball supply.

Replacement of the steam jet during modifications of the steam jet riser would benefit the balancing of water in the tank, stated in the previous section, as well as potential for increased efficiency of a newer steam jet model.

5.5 Surrogate Solids

The entire wash-ball/directional nozzle system removed approximately 99.2% by volume the solid material from the mockup tank. The directional nozzle system brought the sludge height from 0.89 in. to below .06 (1/16) in. Since the directional nozzle system is quite effective in removing the stubborn accumulated solids, future work should include the design and testing of a directional nozzle system. It is also desirable to ensure suspension of the solids by achieving an adequate depth (about 1 inch) of liquid over the bulk of the solids to fluidize the solids for removal via the steam jet (see Figures 12 and 13).

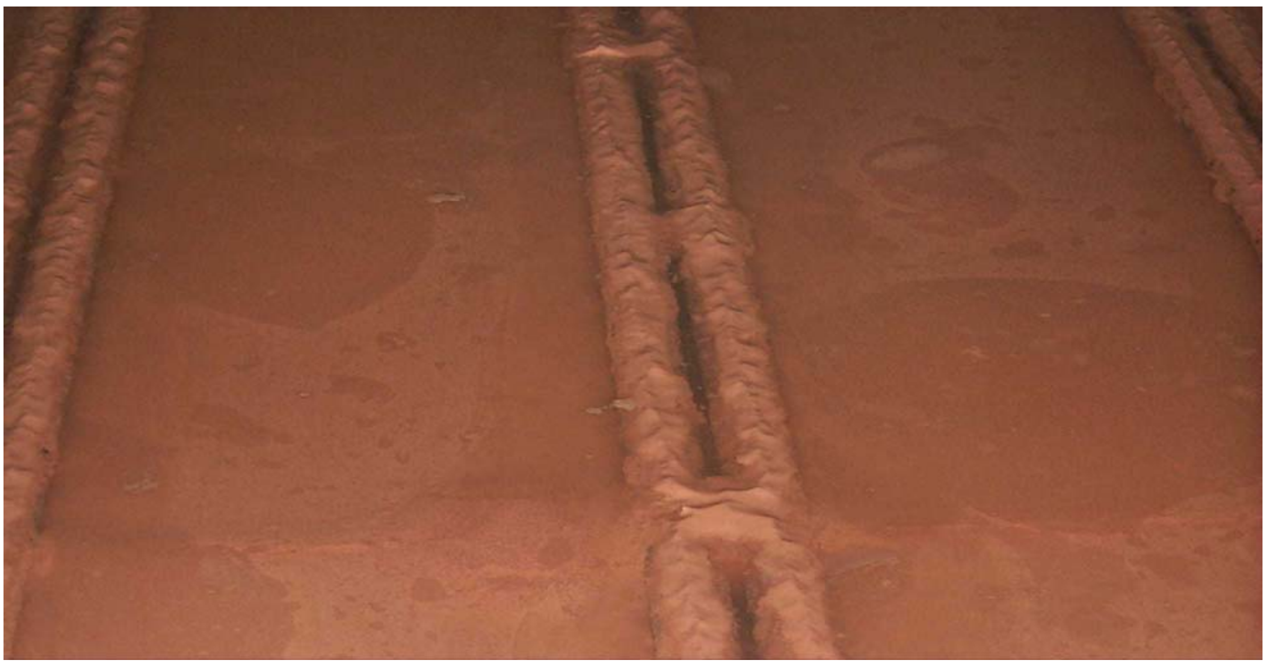

Figure 12. Mockup tank floor cooling coils covered with surrogate solids and water.

Figure 13. Mockup tank wall cooling coils covered with surrogate solids.

5.6 Slurry Pipe Flow Mockup Testing

High concentrations of surrogate solids were pumped successfully through sections of clear piping, elbows, and simulated valves. No blockage in the discharge line occurred. The steam jet was stopped and restarted while transferring the high solids loading. No problems occurred during the testing (see Figures 14 and 15).

At the simulated valves the solids accumulated on the upstream side and flow remained continuous. During actual tank cleaning, all valves should be fully opened to allow unimpeded flow. The solids pumped by the steam jet were at a high concentration, exceeding the upper limits of the TFF transfer flows allowed. This was to present the conditions that exceed the practical limits of the actual TFF transfer limits. As stated in the previous section the maximum concentration level transferred through the mockup transfer line was 5 ½ times greater than the allowed limit in the TFF steam jet and piping system. A video is available that recorded the flow of the slurry through the simulated line.

Figure 14. Slurry Pipe, Simulated Valves and Start of Clear Section

Figure 15. Clear pipe for Mockup solids transfer testing.

6. FY 2000 MOCKUP TEST PLANS AND RISKS

6.1 FY 2000 Test Plans

The FY 2000 Tank Farm Facility (TFF) mockup testing initially proposed several tests. The large scale testing was completed and provided important information for the overall TFF closure. Due primarily to budget constraints, a number of the mockup tests were not initiated. The Mockup test plan outlines each of the proposed tests. The testing that was completed dealt primarily with the washing system and those systems directly supporting the tank washing. The testing associated with tank grouting and the riser interface was omitted as necessitated by budget and schedule constraints.

The proposed mockup testing is listed as follows:

- Fix free liquids will evaluate absorbent performance. It is anticipated that some free liquid will remain after grout placement within the tanks. Testing will determine the dispensing method, the absorption performance in different PH levels and compressive strength of the absorbent as well as other characteristics during and following application

- Riser interface equipment testing verifies the expected performance of the adapter for assembling the video camera/wash ball and wet and dry pipe system flanges. The riser interface interacts directly with the video and wash ball systems. The riser interface adapter connects directly to the riser flange and is secured by swing bolts. The video camera/wash ball system flange mates directly to the riser interface adapter. The video camera is connected to a pole and the wash ball is supported by the supply water pipe. The specialized camera and wash ball flange allows rotation of the camera and wash ball powered by an electric linear actuator. The riser interface adapter also contains the nozzle spray ring assembly. This spray ring assembly cleans the pole/pipe and equipment extracted from the riser

- A grout-placement arm will be designed and built to test the placement of grout at two locations in each tank. These two locations are through two risers located on opposing sides of the tank and are approximately four feet from the tank wall. The grout placement arm is designed to place grout within a radius of ten feet from the tank riser centerline. The grout placement arm consists of a mounting fixture, rotating mechanism, articulating system and delivery line

- Tank washing and mixing of surrogate solids will determine the efficiency of the washing system as well as the functional performance of the support systems. The washing and mixing will test the *wash ball* and the overall solids removal from the tank

- Steam jet testing will determine the performance of surrogate solids transfer from the tank and establish coordination with the washing and mixing systems

- Grout displacement of solids/grout qualification will quantify the amount of residual heel removed from the tank and the amount of residual heel remaining after grouting the tank bottom. Grout placement in the tank will displace a portion of the residual heel to the steam jet pump. There is no expectation that all of the residual heel will be removed from the tank. This test will also evaluate the effect of residual heel on the integrity of the cured grout

- Video camera equipment and systems testing will demonstrate the effectiveness of the camera operation during tank closure procedures. Testing will further verify the capabilities of the camera operation and ability to provide remote monitoring during tank washing.

6.2 The Mockup Testing Not Completed and Associated Risks

The mockup testing that was not done at this time included: the fix free liquids tests, riser interface equipment, the grout placement arm, and the grout displacement of solids/grout qualification. The FY 2000 mockup testing was conducted at the Meltran Facility in Idaho Falls. This facility housed the following tests: (a) tank washing and mixing, (b) the video camera and (c) the steam jet. The mockup testing provided valuable performance data on the systems tested.

Omitting testing of the fix free liquids, riser interface equipment, the grout placement arm, and the grout displacement of solids/grout qualification presents risks. Performing those mockups that were excluded will reduce cost by minimizing performance uncertainties. The information gained from each of the mockup tests has the potential to impact other tank closure systems. The anticipated risks of each mockup test not performed are detailed as follows:

- For fix free liquids, the testing would provide information on the performance of the absorbent on free liquids, the most effective application method, any associated problems with each method selected, and finally the compressive strength after application. These issues affect the type of absorbent selected and the behavior of the absorbent on varying free liquid conditions. Application of the absorbent is important to determine dust problems that may affect the existing or specially installed filtration equipment. We can also determine the actual ability to apply absorbent to the locations necessary and the amount of absorbent required based upon the effectiveness of the application method. These tests will identify the behavior of the absorbent and effect on in situ compressive strength in areas of over application or in areas where free liquids are not present. Determining and comparing the actual compressive strength of the absorbent based upon the different application methods will also be possible. The additional information from the tests above, highlight the risks involved with not performing the fix free liquids testing.

- For the riser interface, the risks involved are potential problems with the installation and mating of components. Operation of the equipment and ease of operation, i.e. rotating the wash ball and video camera. The efficiency of the spray ring assembly at various water pressures and the ability to contain contamination within the tank riser. Extraction and removal of the systems inside the riser interface and removal of the riser interface from the perspective of contamination containment.

- There are risks with the grout placement arm. Similar to the risks involved with the riser interface, the installation of the grout placement arm and mating of components is important to determine prior to actual installation to minimize problems and contamination exposure. Risks also include predicting the performance of the delivery system and overall control of the placing the grout at specified points in the tank. The behavior of the grout flow through the arm and the energy/velocity gain from dropping the depth between the riser at the surface and the tank floor. Control of the grout placement may be the primary issue.

- The grout displacement of solids/grout qualification is important. The impact of not performing the grout displacement of solids is in not having the data necessary to calculate the amount of residual heel left in the tank. Understanding the amount of residual remaining in the tank after grout placement will provide information to calculate the range of contamination remaining within the tank. This will contribute to determining acceptable levels of solids after the final closure and determine the degree of solids removal for the procedures prior to grout placements. Understanding the physical displacement characteristics of the process will impact other closure procedures. Based upon the displacement performance the washing duration may be adjusted for optimal efficiency related to the entire closure process. As an example, if the grout effectively displaced the solids then less time would be required in washing thus reducing water generation and less time using specialized washing procedures, i.e. directional nozzles. An advantage to performing this test would be documentation supporting a predetermined allowable level of solids in the tank to stop washing and begin grout placements. Other factors may be potentially impacted that are not addressed here.

- The risk, related to not performing the grout qualification, is the lack of experimental information to support cured grout integrity.

APPENDIX A

FY-2000 Tank Farm Closure Mockup Test Report Engineering Design File EDF-15722-048

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APPENDIX B

Surrogate Sludge Material Ordering Information

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Surrogate Sludge Material Ordering Information

- products to be used by contactor mixing surrogate sludge materials

Kaolin Clay (WILKLAY FE):

Quantity to order:	12 tons
Packaging:	50-pound bags
Vendor:	Wilkinson Kaolin Associates LTD.
POC:	Carmen Riggs
Phone:	912-628-5301
Price:	*$1, 050*

(price includes pallets, shrink wrap, and under 15 ton cost increase per ton – 15 tons would be $1,140 [under 15 tons = $90/ton, 15 tons + = $70/ton])

Freight	*$2,750* estimate

(Full truckload carrier less expensive and quicker delivery than Less than Truckload Carrier)

Delivery time	3 days

Aluminum Sulfate (Standard Ground, Technical Granular):

Quantity to order:	700 pounds
Packaging:	50 pound bags (solid preferred over liquid per Ready Valley Mix, 14 bags)
Vendor:	Van Waters & Rodgers (Pocatello)
POC:	Robert
Phone:	238-8319
Price:	*$367.50* - includes delivery to Idaho Falls
Delivery time	2-3 days from Denver (solid)

Iron Oxide (Bayferrox 110, Brick Red):

Quantity to order:	500 LB.
Packaging:	25-pound bags

Vendor:	Color Tile & Abrasive
POC:	Drew Peterson
Phone:	801-486-3141
Price:	*$825* ($1.65/lb)
Shipping:	about *$100*?
Delivery time	1-2 days

APPENDIX C

Procedure for Mixing Materials for Making the Mockup Surrogate Sludge

APPENDIX C

Procedure for Mixing Materials for Making the Mockup Surrogate Sludge

Procedure for mixing materials for making the surrogate sludge for use in mockup operations in support of INTEC TFF closure

Background:

A surrogate (artificial) sludge needs to be prepared to mimic characteristics of sludge present in tanks located within the Idaho Nuclear Technology & Engineering Center (INTEC) Tank Farm Facility (TFF) located within the Idaho National Engineering & Environmental Laboratory (INEEL). In order to assess the effectiveness of certain equipment which may be used during planned future TFF closure operations a "mockup" demonstration is required. It is envisioned that cement-mixing trucks are suitable for batch-mixing materials to make the surrogate sludge.

Cement mixing trucks shall be used to mix water, kaolin clay (dry clay), iron oxide (dry pigment powder), and aluminum sulfate (dry small granules). This resultant mix (following the sequence outlined below) will be mixed and poured as two separate jobs to be performed at different times. The first job (Job 1) shall mix and pour 5 batches of 8.00 yards of material into a 25 foot radius mockup "half-tank" located within the Meltran building off Tower Road located to the North of Idaho Falls. The surrogate sludge mixed as a result of this first job will be used to assess tank wash-ball spray effectiveness. The second job (Job 2) shall mix and pour 2 batches of 5.00 yards of material into a 50 ft diameter shallow open tank mockup located just outside and to the north of the Meltran building. The surrogate sludge mixed as a result of this second job will be used to assess grout displacement. Quantities of materials to be mixed are outlined in *Table 1*.

Maximum material loading in the mixing trucks will be 8.00 yards primarily due to the light slurry characteristics of the resultant mix, which may slop at higher loading amounts (possible with the trucks designed for more viscous and dense traditional cement/grout mixtures). In addition, loading with 8 yards will provide for enhanced mixing per rotation time relative to higher loads (say 9 yards). This may be prudent as adequate mixing (dispersion) of kaolin clay with water may provide increased mixing challenges compared to traditional cement/grout mixtures. The resultant mix will not harden with time so hardening time is not an issue.

Refer to all Material Safety Data Sheets before executing this procedure.

Materials required and initial quantity:

Water (Valley Ready Mix water - volume metered)

Kaolin Clay (WILKAY FE) - 12 tons, 480 50 pound bags of dry kaolin clay

Iron Oxide pigment (Bayferrox 110, Brick Red) - 500 pounds, 20 25 pound bags

Aluminum Sulfate (Standard Ground, Technical Granular) - 700 pounds, 14 50 pound bags

[Aluminum Sulfate is also known as "alum"]

Procedure:

Job 1 (25 foot radius “half-tank” inside Meltran building):

1. Fill the mixing truck with 1404 gallons of water.

2. Open and place into the mixing truck 65.8 50-pound bags (3,292 lbs.) of Kaolin clay.

Open and place into the mixing truck 3.2 25-pound bags (79 lbs.) of Iron Oxide pigment.

Mix the contents within the cement truck for at least 30 minutes.

Open and place into the mixing truck 2.1 50-pound bags (103 lbs.) of aluminum sulfate*

Wash down adhered material residuals with 50 gallons of water into mixing truck.

Mix the contents within the cement truck for at least 15 minutes.

Pour the water/kaolin/iron oxide/alum mixture into the 25-foot radius “half tank” through the port on the side of this mockup tank designed for this purpose.

Repeat steps 1 through 8 <u>two</u> additional times with the quantities of materials specified.

Wait two working days to continue Job 1 unless directed by an INEEL representative to continue earlier. [The surrogate sludge solids must adequately settle to the bottom of the half-tank in order for INEEL personnel to decant the liquid off the top of the settled sludge. This settling and decanting time is expected to take two working days. If this procedure is not followed with the present liquid capacity half-tank design height of 10 inches, water and suspended surrogate solids will overflow out of the half-tank and onto the Meltran building floor.]

Ensure an INEEL representative grants permission to proceed with Job 1.

Repeat steps 1 through 8 <u>two</u> additional times with the quantities of materials specified.

End of Job 1

*As indicated in this procedure, the aluminum sulfate must be added after the water, kaolin clay, and iron oxide pigment have been mixed.

Job 2 (50-foot radius shallow open tank outside of the Meltran building):

Ensure an INEEL representative grants permission to proceed with Job 2. [It is planned to removed aged surrogate sludge from Job 1 and replace with new surrogate sludge.]

Fill the mixing truck with 859 gallons of water.

Open and place into the mixing truck 41.1 50-pound bags (2057 lbs.) of Kaolin clay.

Open and place into the mixing truck of 2.0 25-pound bags (50 lbs.) of Iron Oxide pigment.

Mix the contents within the cement truck for at least 30 minutes.

Open and place into the mixing truck 1.3 50-pound bags (64 lbs.) of aluminum sulfate.

Mix the contents within the cement truck for at least 15 minutes.

Wash down adhered material residuals with 50 gallons of water into mixing truck.

Pour the water/kaolin/iron oxide/alum mixture into the 50-ft diameter shallow open tank mockup located just outside and to the north of the Meltran building. The mix should be quite self-leveling after being dispensed from the mixing truck chute. However, add the second batch (next step "10.") to the opposite end of the tank.

Repeat steps 2 through 9 one additional time with the quantities of materials specified

End of Job 2

*As indicated in this procedure, the aluminum sulfate must be added after the water, kaolin clay, and iron oxide pigment have been mixed.

Commentary:

Mixing on a laboratory scale provided indication that mixing should be reasonably simple to achieve and provided the recipe and quantities of materials to be used. However, this mockup procedure may need to be revised due to unforeseen circumstances. A change in procedure or sequence may result in an increase of scope, budget, and schedule within the contract for mixing the surrogate sludge. The quantity of material addressed for Job 1 is anticipated to equate to eight inches of sludge after several days of settling. If for any reason this sludge depth is not realized, Job 1 may be expanded to include additional decanting, mixing, and pouring to ensure eight inches of sludge. The quantity of material addressed for Job 2 is anticipated to equate to one inch of sludge after several days of settling.

Using the quantities outlined in this procedure will result in a surplus of kaolin clay, iron oxide pigment, and aluminum sulfate. Excess materials were ordered as back-up material for unforeseen circumstances, such as unexpected sludge compression within the half-tank mockup, sludge fouling, etc. The environmentally benign surrogate solids make-up materials are not expected to pose a disposal challenge. Kaolin clay may leave a residue on the inside walls/fins of the mixing truck that should very easily be scoured by sand/gravel at the end of this job.

Table 1.

Surrogate Sludge Recipe/Batch Quantities

JOB 1

Quantity for 8 yard batch for Half-Tank Mockup					
Water (gal)	**Kaolin (lb.)**	**Alum (LB)**	**Iron Oxide (LB.)**	**Sludge (gal)**	**Total Volume (gal)**
1,454	3,292	103	79	991	1,616

Bags for Half-Tank Mockup (per batch)		
Kaolin	**Alum**	**Iron Oxide**
65.8	2.1	3.2

Quantity for Half-Tank Mockup (5.0, 8.00 yard batches)					
Water (gal)	**Kaolin (LB.)**	**Alum (LB.)**	**Iron Oxide (LB.)**	**Sludge (gal)**	**Total Volume (gal)**
7,271	16,459	516	397	4,956	8,079

JOB 2

Quantity for 5 yard batch for Grout Displacement Mockup					
Water (gal)	**Kaolin (LB.)**	**Alum (LB.)**	**Iron Oxide (LB.)**	**Sludge (gal)**	**Total Volume (gal)**
909	2057	64	50	620	1010

Grout Displacement mixing divided into two equal batches to enhance mixing and for simplicity. One batch would exceed the maximum desired truck loading.

Bags for Grout Displacement Mockup (per batch)		
Kaolin	**Alum**	**Iron Oxide**
41.1	1.3	2.0

Quantity for Grout Displacement Mockup (2.0, 5.00 yard batches)					
Water (gal)	**Kaolin (LB.)**	**Alum (LB.)**	**Iron Oxide (LB.)**	**Sludge (gal)**	**Total Volume (gal)**
1818	4115	129	99	1239	2020

APPENDIX D

Subcontractor Data

APPENDIX D

Subcontractor Data

APPENDIX E

Slurry Pipe Mockup Drawing

APPENDIX E

Slurry Pipe Mockup Drawing