Grout Testing to Support Tank Closure at the Savannah River Site – 15370

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ABSTRACT

Final operational closure of the Savannah River Site (SRS) waste tanks is performed by filling the voids inside the tanks with a series of tailored grout formulas thereby stabilizing the remaining residuals. These tailored grout formulas were each developed to meet the demands of the closure process. The needs identified for the closure process include (1) a flowable, self-consolidating, reducing grout for tank fill, (2) a highly flowable grout capable of filling the 7-1/4 kilometers (4-1/2 miles) of 5-centimeter (2-inch) diameter cooling coils inside the tank, and (3) a highly flowable grout capable of filling equipment remaining in the tank. The specific characteristics of each of the grout formulations were tested to ensure they would function as required during implementation. Performance testing was also done on some of the grout formulations to confirm mix effectiveness and improve worker handling proficiency and conducted additional testing on the bulk fill grout to expand the placement capabilities of the grout. This paper focuses on the evolution of the closure process' identified needs, formulation development, and the subsequent testing of the tailored grout formulations utilized in the past tank closure processes at SRS.

INTRODUCTION

The Savannah River Site (SRS) has 51 underground tanks which were created to store and process the legacy radioactive liquid waste resulting from Cold War processing. These tanks range from approximately 3M liters to 6.4M liters (750k gallons to 1.3M gallons) and contain waste in the form of sludge, salt cake, and supernate. The waste is processed and disposed of either in a glass matrix at the Defense Waste Processing Facility (DWPF) or in grout form at the Saltstone Facility and the effluents are evaporated at the Effluent Treatment Facility (ETF). As the waste is disposed of and the overall volume is reduced, the individual tanks are no longer needed and can undergo a closure process. During this process, the tanks are cleaned to the maximum extent practical (MEP) and then isolated for final closure.

In the operational closure phase, a specifically designed grout formula is used to fill the tanks which serves three primary purposes: to minimize the transport of radionuclides, to provide an intruder barrier, and to maintain the tank structure. To minimize the transport of radionuclides, a grout formulation with a low hydraulic conductivity is desired. It is also desired to have a grout with a low redox potential to prevent the oxidation of certain long lived radionuclides that are more prone to transport from the waste tank once they are oxidized. To provide the intruder barrier, a grout with a compressive strength in excess of 13.8 MPa (2000 psi) is desired. In addition, to support the tank structure a grout in excess of 3.45 MPa (500 psi) is needed.

In order to effectively fill these contaminated, underground tanks the grout must be able to be delivered to the tank and effectively spread with no agitation. This requires the use of a self-consolidating grout with a high slump flow. In addition, due to the amount of grout being poured, the heat of hydration must be minimized to prevent damage due to overheating. It must also be a non-shrinking grout to prevent fast paths for water intrusion and be a zero-bleed water formula to prevent the costly recovery and treatment bleed water from the contaminated environment.

In addition to the bulk fill grout, it is also required that the cooling coils and void spaces in equipment remaining in the tank be grouted. This grout is required to meet the requirements of the bulk fill grout, but presents unique challenges for the delivery of the grout given the varying geometries of the equipment.

The formulations and strategies to meet these requirements have evolved over the years and have undergone significant changes between each of the tank closure campaigns. The initial research and development phase was conducted prior to the closure of Tanks 17F and 20F in 1997. Following the closure of these tanks, a significant amount of time passed as federal and state regulators evaluated future tank closures. During this time, significant testing and research was performed which improved the grout formulations and grouting process. In 2012, Tanks 18F and 19F were closed using the new grout design and strategies. This was followed by the closure of Tanks 5F and 6F in 2013. Each of these closure campaigns yielded lessons learned and resulted in new formulations, testing, and strategies.

TANK 17F AND 20F GROUTING

Strategy and Testing

The initial strategy for tank closure included a layer of reducing grout, a layer of Controlled Low-Strength Material (CLSM), and a layer of strong grout. The purpose of the reducing grout was to cover the remaining sludge layer in the tank and reduce the mobility of certain radionuclides. [1] The formulation for this grout was developed through a series of tests of multiple grout formulations. This testing included freefalling the material from heights of 0.6 meters (2-feet) and (1.5 meters) 5-feet as well as evaluating the spread of the material in a form with a length of 27.4 meters (90 feet). Ultimately it was shown that a formulation containing Type V portland cement provided the most "forgiving" formulation with respect to placement and stabilization requirements. [2]

One concern identified during the testing of the grout formulations related to its impact on the residual sludge in the tank. The testing showed that the placement of the reducing grout on the remaining sludge layer was causing the existing sludge layer to be pushed to the edges of the tank and on top of the grout which would prevent the material from being immobilized by incorporating with the grout. In order to address this concern, additional testing was performed in a scaled tank test area. This developed a strategy to pour reducing grout from several outside locations (instead of one central location), then to add a layer of dry grout to incorporate the remaining liquid, followed by another layer of reducing grout. This strategy was shown to be capable of capturing the residual waste and alleviating the aforementioned concerns. [3]

The CLSM utilized for the bulk of the tank fill was chosen because of its extensive use on site, low expense, low heat of hydration, and its compressive strength to support the over burden.[1] While this was a readily used material, it also posed a challenge in the amount of bleed water it produced (~ 10% of the total mixing water). In order to address this concern, over 30 mixes of CLSM were tested to determine which would provide the required properties while eliminating the bleed water concern. This testing resulted in the identification of a mix which utilized a polymeric thickener to maintain flowability with the lower water content. [4]

The final layer of grout, the strong grout, served as an intruder barrier. This grout was to have a strength that would prevent inadvertent access to the tank in the future if institutional control were lost. This grout has a compressive strength closest to that of normal concrete (13.8 MPa [2,000 psi]).

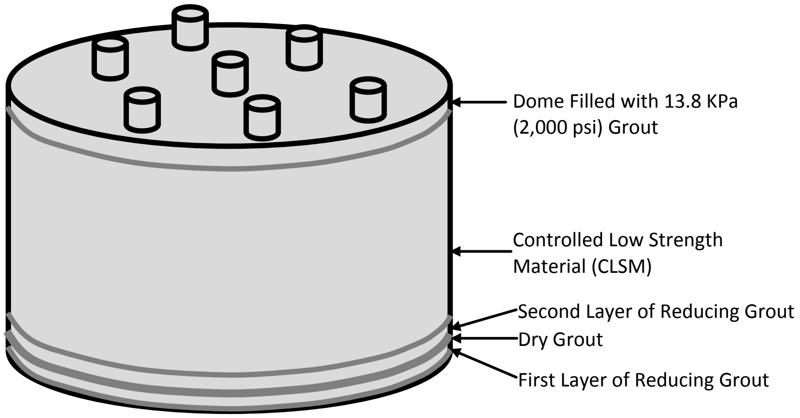

Figure 1 – Tank 17F/20F Grout Strategy

The grout was produced on site by a temporary batch plant and was pumped through a 12.7 centimeter (5 inch) slick line to the waste tanks. A diversion box was used to route the grout to the different risers. [5]

Results and Lessons Learned

Several lessons learned were developed based on the experience from grouting Tanks 17F and 20F. [5] First, the batch plant used proved costly for labor and materials. This was primarily due to the multiple grout formulations which required repeated switching of materials. Better coordination of grouting efforts was utilized for Tank 17F than for Tank 20F which saved money. Also, for Tank 17F a grout pumper truck was utilized as opposed to a grout junction box which had been used on Tank 20F. This resulted in a reduction in the cost of labor and materials. Finally, it was recommended that a simplified grout formulation be developed to reduce cost (i.e. a “one grout formula”).

TANK 18F AND 19F GROUTING

Waste tank closure was scheduled to continue in the years following the closure of Tanks 17F and 20F, however the litigation brought forth by the Natural Resources Defense Council (NRDC) challenged the methodology used by the DOE for classifying the remaining waste in tanks and resulted in litigation which extended into 2004. During the time of this litigation, no tanks could be closed which delayed the planned activities. In addition, the resolution to the litigation resulted in rule changes which required new permitting requirements and a new Maximum Extent Practical (MEP) methodology for demonstrating waste removal. The implementation of these requirements resulted in a significant delay in waste tank closures at SRS and across the DOE complex. The next waste tanks closed, Tanks 18F and 19F, were not closed until 2012.

Strategy and Testing

The significant delay in waste tank closures allowed for a significant amount of testing to be performed to incorporate the lessons learned from the earlier tanks closures.

One of the primary lessons learned from grouting Tanks 17F and 20F was the complications introduced from having multiple grout mixes. In 1998, the first “all-in-one” grout mix was developed that could be used as a reducing and bulk fill grout. This CLSM was developed by substituting Grade 100 slag for some of the fly ash in the formulations used in previous waste tank grouting. This resulted in a single mix that met both chemistry requirements for encapsulating the waste as well as placement requirements for bulk filling the tank. [6]

As a part of the new closure requirements brought about by the litigation, a Performance Assessment (PA) was required to be developed which modeled the performance of the grout overtime and the transport of the residual material in the tank to the surrounding environment. As an input to the PA, further testing was performed on the "all-in-one" grout and the tank vault concrete to determine the performance of the grout and waste tank over time due to chemical degradation. This evaluation determined the environment surrounding the grout to be benign and the potential for chemical degradation to move at a slow rate; limited by the ability of the chemical species to penetrate the grout. The primary chemical attack was determined to come from carbonation. Carbonation is the reaction between atmospheric carbon dioxide and the calcium hydroxide in the concrete which forms calcium carbonate. The calcium carbonate may actually increase the strength of voids in the concrete, but also lowers the alkalinity of the concrete which allows for corrosion for rebar and cooling coils which may present fast flow paths through the grout matrix. In addition, the iron oxide compounds formed are expansive compounds and may introduce cracking into the grout. Carbonation is limited by the availability of the concrete to interact with the carbon dioxide and therefor is limited in its impact to the top layer of the grout. In addition, the bulk fill grout does not contain rebar so the negative impacts from this reaction are only present in the concrete vault which contains rebar, the waste tank itself and the tanks containing cooling coils. The cracking as a result of the expansive iron compounds is not expected to be immediate and will not occur until long after the carbonation has occurred. However, if this does occur, the rate of hydraulic conductivity is anticipated to increase to that of the surrounding soil. [7]

Additional testing was performed to minimize the hydraulic conductivity of the grout by modifying the formulation. In 2007, testing was performed to evaluate the currently identified grout mixes for new admixtures which had been modified or replaced with alternatives. This testing evaluated the grout mixes for hydraulic conductivity, compressive strength, and leaching and also developed two alternative mixes to be considered as potential improvements. The results of this testing identified the current grout mixes barely exceeded minimum requirements for compressive strengths and had hydraulic conductivity values that could be improved upon with alternative grout mixes. The alternative grout mixes improved upon this formulation by providing a grout with a lower water to cement ratio (w/cm) and by reducing the aggregate surface area by replacing approximately half the sand with 0.9525 centimeter (3/8 inch) aggregate. A High Range Water Reducer (HRWR) was utilized to reduce the water required while maintaining the flowability of the grout. These alternative mixes produced favorable results for significantly increased compressive strength and lowered hydraulic conductivity. The following requirements were established for the design of the low permeability, flowable grout for SRS tank closure:

- Highly flowable material
- No bleed water
- Low permeability
- Low heat of hydration for mass pour application
- Low w/cm ratio
- Set time that can be adjusted to minimize cold joint assuming daily pours
- Production rate of at least 459 cubic meters (600 cubic yards) per day [8]

Further testing was recommended for the alternative mixes and was performed in 2011 which evaluated alternative mixes to reduce the heat of hydration and incorporate positive attributes of flowable fill grouts used in the closure of P- and R-Reactor at SRS. Three primary series of grouts were developed for this testing; a modification to the existing grout to address admixtures to lower the heat of hydration and viscosity, a sand only mix which contained no aggregate and a series based on a modified recipe of the reactor flowable fill grout. The modification to the existing grout was not successful as the admixtures to reduce the hydraulic conductivity resulted in a grout with a high viscosity which is not conducive to spreading over the surface of an eighty-five foot diameter tank. The sand only mixes performed well, with flows only slightly less than those containing gravel. However, previous experiences with similar mixes containing sand only required admixture adjustments which may prove problematic if the grout were prepared and trucked from offsite. The best and most preferred grout was determined to be the grout based on the reactor fill grout. The formulation used for filling the reactors was not directly transferable to waste tank closure due to the chemistry and compressive strength requirements, but was ideal based on the flowability, ability to self-level and zero bleed characteristics. The formulation was adjusted to meet closure needs by adjusting the w/cm ratio, adding slag, and adjusting the cement content. The resulting grout formulation had a high compressive strength, a high slump flow, and a low hydraulic conductivity which are all preferable for waste tank closure. [9] This grout, designated LP#8-16, was selected for the bulk fill of Tanks 18F and 19F.

Delivery

Grouting into Tanks 18F and 19F was performed through a single, center riser. This was anticipated to be successful based on the experience in Tanks 17F and 20F. Instead of the multiple grout formulations previously used, these tanks were filled with the single "all-in-one" grout formulation and unlike the previous tank closures, no dry mix was used in filling these tanks. Previous grouting evolutions showed the ability of the grout to encapsulate the residual material without the use of this dry material. If it were determined additional pour locations were required to cover the residual material, provisions were made for them to be designed and installed to address the area of concern. [10]

The grout was delivered to the tanks using a portable grout pump that is commercially available and was fed from grout mixer trucks in place of the onsite batch plant previously used

Equipment Grouting

Tank 18F and 19F offered a new challenge with a significant amount of equipment remaining in the tank from bulk waste removal and heel removal campaigns. It was determined this remaining equipment would not be removed and would be grouted in place. However, the internals of this equipment represented a vertical fast path which was required to be filled with grout to the extent practical. The remaining equipment included an Advanced Design Mixer Pump (ADMP), a telescoping transfer pump and discharge pipe, standard mixer pumps and evaporator feed pump educator lines. [10] The potential for grouting the equipment was evaluated using previously identified grout containing a mixture of Masterflow® 816[a]. While this mix does provide a highly flowable material, the adiabatic heat of hydration exceeded the target value and was deemed not appropriate for large equipment. An adjusted mixture with fly ash substituted for the Masterflow® 816 was identified and tested through a mock up to demonstrate its ability to adequately fill the bounding equipment configuration. [11]

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[a] Masterflow® is a registered trademark of BASF Corporation.

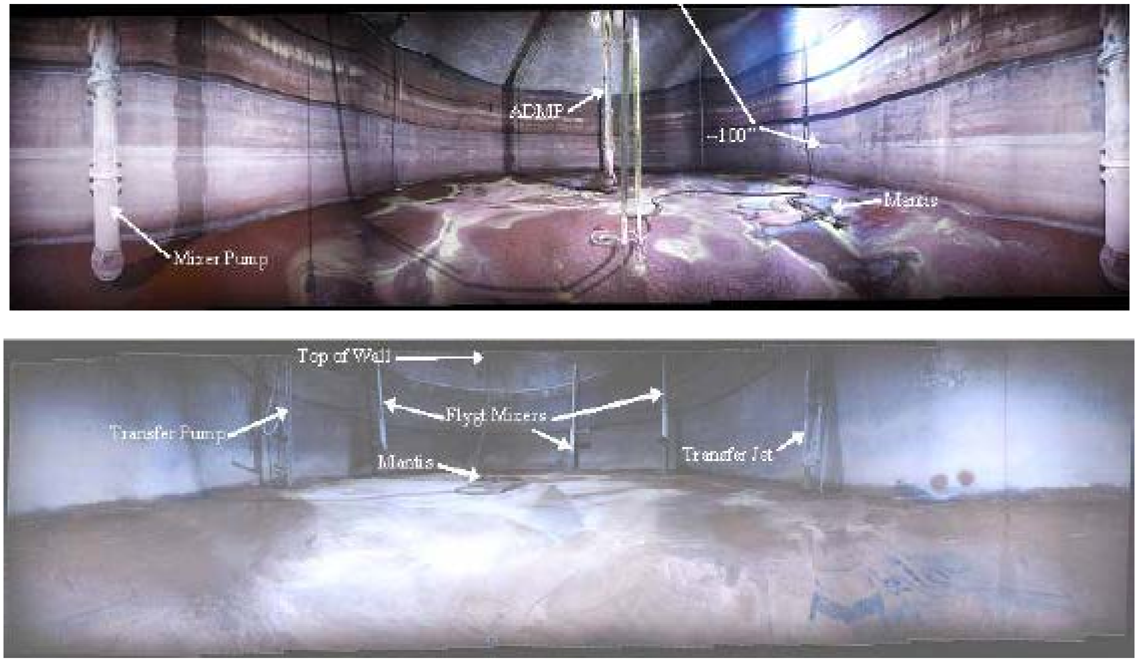

Figure 2 - Tank 18F and 19F Remaining Equipment

Results and Lessons Learned

Tanks 18F and 19F were successfully grouted based on the identified strategy. Lessons learned were primarily related to the equipment grouting in view of the coming grouting of cooling coils on Tanks 5F and 6F. The grouting of the equipment was performed by mixing the grout on site which required a considerable amount of labor and use or respirators. While this was limited on Tanks 18F and 19F due to the limited amount of equipment on these tanks, this would be a significant challenge when trying to fill the cooling coils in Tanks 5F and 6F. Additionally, the mixer used for equipment fill grout was a colloidal mixer which introduced significant heat to the grout while being mixed, which in turn impacted the set time of the grout and limited the time allowed for placement.

TANK 5F AND 6F GROUTING

Tanks 5F and 6F were the next tanks closed after Tanks 18F and 19F. The same grout was used for these tanks as was used for the previous tanks, but a different pour strategy was utilized. Additionally, these tanks were significantly smaller than the previous tanks (approximately 3M liters to 6.4M liters [793k gallons verse 1.7M gallons]), but offered unique challenges because these were the first tanks grouted containing cooling coils.

Grout Strategy

The pour strategy for these tanks required pouring from multiple risers as opposed to the single riser pour location utilized for Tanks 18F and 19F. This was due to the significant amount of equipment remaining within the tank that could obstruct the grout flow. The primary obstructions were the kilometers of cooling coils within the tanks. It was determined that four pour locations would provide adequate coverage to provide a relatively level grout surface. The slickline was configured such that sections of the pipe could easily be rerouted from one riser to another.

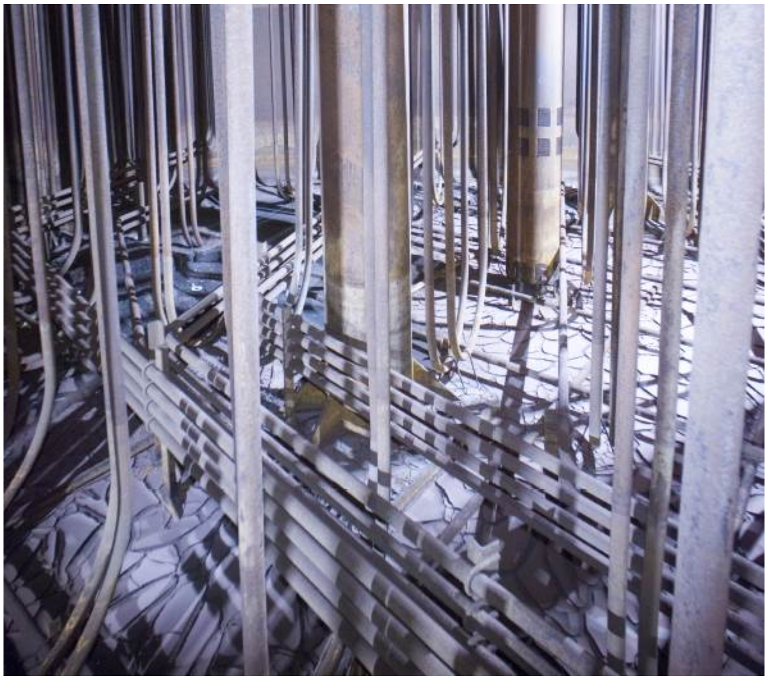

Figure 3 - Tank 5F Cooling Coil Obstructions

Additionally, Tanks 5F and 6F had an annulus to be grouted that was not a part of the previously grouted tanks. The annulus was grouted in a similar fashion to the primary tank. In order to ensure structural integrity of the primary tank wall, the differential height between the grout in the primary tank and the annulus was required to be managed as a part of grouting to prevent over stressing and potentially collapsing the wall. This was managed by a combination of visual observation and anticipated grout volumes. [12]

Cooling Coil Grouting

The cooling coils were included in the tank design to control the liquid waste temperature increase due to the heat generated from radioactive decay. In each of these tanks, there are a total of thirty-six cooling coils, thirty-four of which were vertical coils and two of which were horizontal coils. These were made of 5 centimeter (2 inch) diameter pipe and covered approximately 7-1/4 kilometers (4 ½ miles) in the tanks.

Grouting of these coils required a specialized grout mixture and strategy to ensure they were filled to the extent practical. Initial testing was performed to identify the appropriate mix for this application and evaluated commercially available cable grouts mixed with slag as well as a Portland cement/slag mixture using a superplasticizer admixture. The slag was required for each of the admixtures to provide the required reducing capabilities within the grout. All of the mixtures exceeded requirements for hydraulic conductivity and compressive strength, however the testing showed the mix containing Masterflow® 816 and slag was the optimum mixture. The option using Portland cement was not used because of a small amount of bleed water observed immediately after pouring and the potential for shrinkage which may allow for the development of a fast path within the coil. [13]

This optimized cooling coil grout formula was then required to be tested to ensure it would be capable of filling the full length of the cooling coils. This testing was performed by establishing a mockup of a vertical coil and a horizontal coil and filling the coil. The testing showed the grout was capable of filling the coils to a significant degree, but was sensitive to the pumping rate. It was recommended that the cooling coils be flushed with a volume of water two times that of the coil prior to grouting at a flow rate of at least 106 liters per minute (28 gpm) in order to eliminate air trapped within the line prior to grouting. [14]

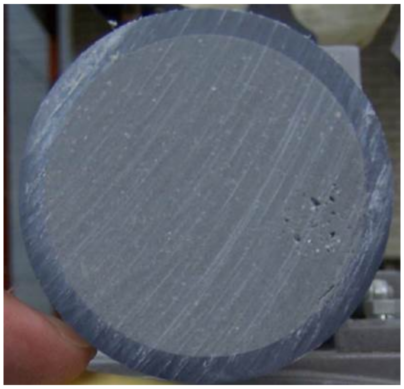

Figure 4 – Cross-section of a Vertical Coil with Minimal Void Space

An additional challenge for cooling coil grouting was the method of onsite mixing. As was learned from equipment filling on Tanks 18F and 19F, the mixing of grout for large equipment was labor intensive and required the use of respirators which is not desirable, especially when grouting during summer months. It was determined the best path was for a vendor to provide the grout in a premeasured container that could be lifted by forklift and loaded into the mixer. This was problematic in that the material identified, Masterflow® 816, had a six month shelf life and the manufacturer stated this shelf life is voided once the original packaging is opened. Through coordination with BASF, the manufacturer of Masterflow® 816, a premeasured quantity including the required amount of slag and deliver it in a Super Sack container which allowed the material to be loaded into the mixer using a forklift. While a worker was still required to wear a respirator to release and empty the bag, it greatly decreased the amount of time the worker was in the respirator and prevented a significant amount of labor required if the material were procured in 22.7 Kg (50 pound) bags.

Lessons Learned

The lessons learned from grouting of Tanks 5F and 6F were primarily related to field implementation and had little to address grout formulations. The only items that required testing to address are potential process improvements to increase the drop height and to potentially allow dropping into a predefined depth of water. These items are process improvements only and no items were identified related to the performance of the grout itself. [15]

RECENT TESTING

The grouting methodologies and formulations used in the past are maintained in a phase of continuous improvement. As a part of this continuous improvement, testing is being performed to improve placement methodologies and better understand the performance of grout. The following is a summary of the recently performed testing.

Grout Drop Testing

The current grout placement practices are limited to a drop height of 1.5 meters (5 feet) or less. This is based on the limitations of past testing and the recommendations of ACI 237R-07 which states to limit the free fall height to prevent entrapped air and segregation. This free fall height is limited by the use of a tremie which is placed to allow free fall of no more than 1.5 meters (5 feet) above the grout prior to initiating a pour. Once the grout height reaches the tremie, it is lowered into the tank and another tremie is inserted at the new proper length. This adds additional worker labor hours and exposure while installing the tremie. Additionally, the tank closure schedule has historically contained a schedule activity which spanned weeks to ensure the tanks have time to dry prior to waste tank grouting. The waste tank closure schedule may be accelerated if this activity is not necessary.

To address these potential improvement items, testing was performed to determine the potential impacts from dropping from the maximum height of a waste tank riser (12.8 meters [42 feet]) without a tremie and into water. This was to determine if these phenomena offered any potential impact to the parameters of concern for waste tank grout. Primarily, the testing was performed to determine if there was any significant difference in the grout being dropped from 12.8 meters (42 feet) using a tremie to limit the free fall difference and dropping from 12.8 meters (42 feet) without a tremie (complete free fall). Both of these drop scenarios were tested by dropping into a dry tank and into a tank containing ten centimeters (four inches) of water. [16]

The initial results of this testing indicate that dropping into ten centimeters (four inches) of water results in an apparent significant amount of segregation. The final report is anticipated in December 2014.

Figure 5 – Grout Drop Testing (Forty-Two Foot Free Fall)

CONCLUSIONS

The closure and grouting of waste tanks has required a significant amount of testing and development to mature the formulation and delivery processes to the point they have reached today. This process has evolved over the past six tank closures as the regulatory framework has changed and the technology has developed. This evolution has enabled the formulations to become more robust and better meet the requirements to safely close the tanks and meet the regulatory requirements.

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