SRNL-STI-2011-00551
Revision 0

Keywords: *Tank Closure*
Concrete

Retention: *Permanent*

Tanks 18 and 19-F Structural Flowable Grout Fill Material Evaluation and Recommendations

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September 2011

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Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

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ACKNOWLEDGEMENTS

URS Washington Group, Quality and Testing Division management and technical personnel provided use of the SRS Civil Engineering Laboratory and test equipment, and technical expertise and input that was essential for performing the tests and obtaining the results in this report. W. Pope, Jr., W. B. Mhyre, and J. T. Waymer, URS, are recognized as key contributors to this project.

J. L. Steimke, H. N. Guerrero, and M. L. Restivo, SRNL Engineering Development, provided the thermal properties for selected mixes. This information was required for designing the tank fill grout formulation. H. N. Guerrero also designed the instrumented shrinkage characterization test forms and designed the test protocol for measuring dimensional changes of the tank fill grout as a function of temperature, time, and relative humidity. This effort supports designing tank fill grouts that minimize fast pathways (cracks and gaps) inherent to conventional cementitious materials.

K. L. Dixon provided moisture retention data needed to calculate relative hydraulic conductivities (as a function of saturation). J. T. Mason, Jr., SRNS Geotechnical Engineering, is the STR for the MACTEC contract and provided an efficient interface with MACTEC.

EXECUTIVE SUMMARY

Cementitious grout will be used to close Tanks 18-F and 19-F. The functions of the grout are to: 1) physically stabilize the final landfill by filling the empty volume in the tanks with a non compressible material; 2) provide a barrier for inadvertent intrusion into the tank; 3) reduce contaminant mobility by a) limiting the hydraulic conductivity of the closed tank and b) reducing contact between the residual waste and infiltrating water; and 4) providing an alkaline, chemically reducing environment in the closed tank to control speciation and solubility of selected radionuclides.

The objective of this work was to identify a single (all-in-one) grout to stabilize and isolate the residual radionuclides in the tank, provide structural stability of the closed tank and serve as an inadvertent intruder barrier. This work was requested by V. A. Chander, High Level Waste (HLW) Tank Engineering, in HLW-TTR-2011-008. The complete task scope is provided in the Task Technical and QA Plan, SRNL-RP-2011-00587 Revision 0.

The specific objectives of this task were to:

1) Identify new admixtures and dosages for formulating a zero bleed flowable tank fill material selected by HLW Tank Closure Project personnel based on earlier tank fill studies performed in 2007.

   The chemical admixtures used for adjusting the flow properties needed to be updated because the original admixture products are no longer available. Also, the sources of cement and fly ash have changed, and Portland cements currently available contain up to 5 wt. % limestone (calcium carbonate).

2) Prepare and evaluate the placement, compressive strength, and thermal properties of the selected formulation with new admixture dosages.

3) Identify opportunities for improving the mix selected by HLW Closure Project personnel and prepare and evaluate two potentially improved zero bleed flowable fill design concepts; one based on the reactor fill grout and the other based on a shrinkage compensating flowable fill mix design.

4) Prepare samples for hydraulic property measurements for comparison to the values in the F- and H- Tank Farm Performance Assessments (PAs).

5) Identify a grout mix for the Tanks 18-F and 19-F Grout Procurement Specification [Forty, 2011 a, b, c].

Results for two flowable zero bleed structural fill concepts containing 3/8 inch gravel (70070 Series and LP#8 Series) and a sand only mix (SO Series) are provided in this report. Tank Farm Engineering and SRNL Project Management selected the 70070 mix as the base case for inclusion in Revision 0 of the Tanks 18-F and 19-F grout procurement specification [Forty 2011 a] and requested admixture recommendations and property confirmation for this formulation [Forty, 2011 b]. Lower cementitious paste mixes were formulated because the 70070 mix is over designed with respect to strength and generates more heat from hydration reactions than is desirable for mass pour application. Work was also initiated on a modification of the recommended mix which included shrinkage compensation to mitigate fast pathways caused by shrinkage cracking and poor physical bonding to the tank and ancillary equipment. Testing of this option was postponed to FY12.

Mix, LP#8-16 is recommended for inclusion in the specification for furnishing and delivering tank closure grout for Tanks 18-F and 19-F [Forty, 2011 c]. A shrinkage compensating variation of this mix, LP#16C, has not been fully developed and characterized at this time. The mix design for LP#8-16 is provided in the table below.

Tanks 18 and 19-F Bulk Fill Material Recommendation.

Mix Number	Cement Type I/II	Slag Grade 100	Fly Ash Class F	Type G Shrinkage Compensating Component	Sand Quartz	Gravel No. 8 3/8 in.	Water	HRWR SIKA Visco Crete 2100	VMA Diutan Gum Kelco-Crete DG
	Lbs/cyd						Gal / cyd	Fl oz / cyd	g / cyd
LP#8-16	125	210	363	0	1790	800	48.5	41	200

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CLSM	Controlled Low Strength Material
cm	centimeter
cyd	cubic yard
EDL	Engineering Development Laboratory
Eh	Oxidation – reduction potential (volts or milli volts)
FFA	Federal Facility Agreement
FTF	F-Area Tank Farm
GSA	General Separation Area
HRWR	High range water reducer
HTF	H-Area Tank Farm
K sat	Saturated hydraulic conductivity (for water at 20°C)
lbs	pounds
PA	Performance Assessment
pH	Negative logarithm of the hydrogen ion activity in solution
psi	pounds per square inch
QA	Quality Assurance
SCMI	South Carolina Minerals Inc.
SRIP	Site Regulatory Integration and Planning
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions, LLC
SRR	Savannah River Remediation, LLC
SRS	Savannah River Site
STR	Subcontract Technical Representative
VMA	Viscosity Modifying Admixture

1.0 INTRODUCTION

Cementitious grout will be used to close Tanks 18-F and 19-F. The functions of the grout are to: 1) physically stabilize the final landfill by filling the empty volume in the tanks with a non compressible material 2) provide a barrier for inadvertent intrusion into the tank, and 3) reduce contaminant mobility by a) limiting the hydraulic conductivity of the closed tank, b) reducing contact between the residual waste and infiltrating water, and 4) providing an alkaline, chemically reducing environment in the closed tank to control speciation and solubility of selected radionuclides.

1.1 Objective

The objective of this work was to identify a single (all-in-one) grout to stabilize and isolate the residual radionuclides in the tank, provide structural stability of the closed tank and serve as an inadvertent intruder barrier. This work was requested by V. A. Chander, High Level Waste (HLW) Engineering, in HLW-TTR-2011-008 [Chander, 2011]. The complete task scope is provided in the Task Technical and QA Plan, SRNL-RP-2011-00587 Rev. 0 [Stefanko, et al., 2011].

The specific objectives of this task were to:

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5) Identify a structural flowable fill mix design for the Tanks 18-F and 19-F Grout Procurement Specification [Forty 2011, a, b, c].

1.2 Background

The FTF is located in the General Separations Area (GSA) of the Savannah River Site (SRS). The FTF includes twenty-two waste tanks constructed between 1951 and 1976. See Figure 1-1. In contrast to Tanks 17F and 20F, which were closed in 1997, Tank 18-F and 19-F will be filled with one grout formulation, a structural flowable fill which is chemically reducing, i.e., an All-In-One mix design [SRR Closure Module, 2011].

Waste removal operations are currently in progress in F Tank Farm to support closure of the non-compliant tanks in accordance with the Federal Facility Agreement (FFA) closure schedule. Heel removal and characterization in Tanks 18-F and 19-F are complete.

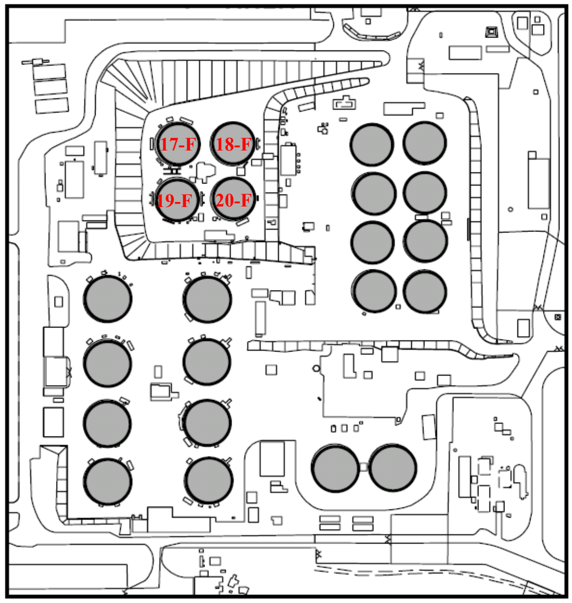

Figure 1-1. General Layout of the SRS FTF.

1.3 Previous SRS Tank Grout Mix Designs

In 1997, two single-shell carbon steel tanks (17-F and 20-F) in the FTF were emptied and filled with grout. Both tanks had a capacity of 1.3 million gallons and were originally used to store low-heat waste. The original concept was to use three different grouts in the closure concept: a high strength reducing grout to encapsulate the residual waste, a Controlled Low-Strength Material (CLSM) [1] for filling the bulk of the tank and, a 2000 psi grout as an intruder barrier in the top of the tank.

The high strength reducing grout was designed by engineers at the Construction Technology Laboratory, Skokie, IL. SRNL modified the original SRS CLSM and 2000 psi grout mixes to eliminate bleed water.[2] Initial testing of the Site CLSM and 2000 psi grout indicated that a significant amount of bleed water would be generated in the closed tanks. Ingredients in the grout mixes used to fill these tanks are listed in Table 1-1 [Langton, et. al, 2001].

In 1998, research was conducted to develop an all-in-one HLW tank fill grout that could be used for both encapsulating the residual waste and bulk fill [Langton and Rajendran, 1998]. The driver for this work was the desire to simplify the production requirements for tank fill material. This work resulted in an all-in-one zero bleed reducing fill/grout mix which is also provided in Table 1-1. This mix was adopted for the Reducing CLSM, Mix No OPCEXE-X-P-0-BS, listed in the current SRS Specification C-SPP-F-00047, Revision 2 [C-SPP-F-00047, Revision 2, 2003].

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[1] CLSM is a cementitious flowable fill that is used as backfill or infill and has soil-like properties. It is self compacting and consequently does not required mechanical compaction to achieve design density. CLSM typically contains sand, fly ash and less than 100 pounds of hydraulic material per cubic yard of fill.

Hydraulic cementitious material reacts with water to form insoluble hydrated compounds. Portland cement is the best known hydraulic cement. Slag cement is also hydraulic once it has been activated.

[2] Eliminating bleed water resulted in eliminating the need for removing and disposing of radioactively contaminated liquid from the tanks. It also reduced settling and stratification which resulted in improved cured properties. Bleed water is not a problem when these materials are used in conventional soil backfill applications where the water can drain off or evaporate.

Table 1-1. SRS Tank Closure Grout Mix Designs from the 1990's [Langton, et. al, 2001].

	Tanks 17-F and 20-F 1997			1998 All-In-One (modification of 1997 flowable fill)	2007 Alternative All-In-One Study
Ingredients	**SRS Reducing Grout**	**SRS Zero-Bleed Flowable Fill**	**SRS Zero-Bleed 2000 psi Grout**	**SRS All-In One Zero Bleed Reducing Fill/Grout** OPCEXE-X-P-0-BS**	**All-In-One Mix 070070** [Langton, et. al, 2007]
Portland Cement Type I/II (lbs / cu yd)	1353	150	550	75	185
Slag Grade 100 (lbs / cu yd)	209	---	---	210	260
Fly Ash, Class F (lbs / cu yd)	---	500	---	375	850
Silica Fume (lbs / cu yd)	90	---	---	---	---
Quartz Sand ASTM C-33 (lbs / cu yd)	1625 (masonry sand)	2300 (concrete sand)	2285 (concrete sand)	2300 (concrete sand)	942
ASTM C-33 No. 8 Stone 3/8 inch Crushed Granite (lbs/cu yd)	---	---	---	---	946
Water (gallons /cu yd) *(lbs/cu yd)*	86.4 *(721)*	63 *(526)*	65 *(542)*	60 *(500)*	61 (506)
HRWR (fl oz. / cu yd)	250	90* Adva Flow	140 Adva Flow	90* Adva Flow	54 Adva Flex
Viscosifier Kelco-crete® (grams / cu yd)**	---	275	275	275	216
Set Retarder (Hydration Stabilizer (fl oz. / cu yd)	150	---	---	---	Up to 4 Recover As required
Sodium Thiosulfate (lbs / cu yd)	2.1	---	---	2.1 (optional)	2.1 (optional)

* Advaflow and Kelco-crete® were premixed prior to incorporation in the zero-bleed mixes rather than adding as individual components.

** This mix was adopted for the Reducing CLSM, Mix No OPCEXE-X-P-0-BS, listed in the SRS Concrete Specification.

In 2006 and 2007 samples of Mix No OPCEXE-X-P-0-BS were prepared and characterized along with several alternative all-in-one mix designs in anticipation of closing Tanks 18-F and 19-F. The results of this work are presented elsewhere [Langton, 2007]. In 2010, one of the alternative grout mixes, Mix No. 070070, was selected by F-Tank Farm Engineering and Closure Project personnel for consideration as the Tank 18-F and 19-F closure grout and for inclusion in revision 0 of the procurement specification for the tank fill grout [Forty, et al., 2011 a].

During 2009 and 2010, flowable structural fill grouts were designed for closing SRS P- and R-Reactor facilities. These mixes were designed to be robust and suitable for high volume placements. Approximately 180,000 cubic yards of flowable structural fill were placed in the below grade portions of the 105 P- and R- Reactor facilities.

This report presents data for Mix No. 70070 per request of F-Tank Farm Engineering in addition to data for developing improved mix designs for closing Tanks 18-F and 19-F. These new grout designs are also all-in-one mixes (compared to the original three layer concept used in Tanks 17-Fand 20-F). These new grouts were designed to address marginal performance of the Mix No. 70070 mix (high reaction heat) and the original sand only all-in-one grout (< 2000 psi after 28 days), respectively. The new grouts combine features of the flowable zero bleed structural fill mix was used in the successful SRS reactor closure projects with chemical features (stabilizing grout) and strength requirements (capping grout) of an all-in-one tank closure grout.

1.4 Tank 18-F and 19-F Grout PA Attributes and General Requirements

The important attributes of the cured tank fill materials, with respect to properties that control leaching (permeability and chemistry), are listed below in a general order of priority:

A. Low water infiltration (conductivity) through the in-place grout, over the long term
B. High reducing capacity, over the long term
C. High long term strength of in-place grout
D. Low long term cracking
E. Low long term degradation of the in-place grout
F. Adequate flowability of the grout during placement.

These attributes for tank closure grouts were combined with and interpreted in terms of engineering properties to derive general engineering parameters. See Table 1-2. The link between the general parameters and the detailed requirements is provided in a separate report [Stefanko and Langton, 2011].

Requirements for fresh slurry properties and cured properties are listed along with the basis for each requirement. Test methods for determine parameter values are also provided. Properties which are required for the F-Tank Farm (FTF) Performance Assessment (PA) are identified.

A short list of current tank closure all-in-one reducing grout requirements was provided by Savannah River Remediation (SRR) F-Tank Farm Engineering in the Technical Task Request (TTR) that controls this work [Chander, 2011]. These requirements were used as criteria for evaluating candidate grout formulations and for designing improved formulations. The expanded list of requirements for tank closure grout is provided in SRNL-RP-2011-00977 and includes: 1) modifications to the short list, 2) the bases for the requirements, and 3) explanation of the requirements and tests needed to support the FTF PA [Stefanko and Langton, 2011].

Table 1-2. Link Between Historic Tank Closure Reducing Grout Attributes, Physical Properties, and Engineering Parameters [from Langton, et. al, 2007].

SRIP Attributes [Newman, 2006]	Physical Property	Engineering Parameter
Low water infiltration (conductivity) through the in-place grout, over the long term	Saturated Permeability less than current tank fill grout	1. Saturated Permeability $K_{sat} \leq$ 2E-08 cm/sec 2. Durable
High reducing capacity, over the long term	High long-term negative Eh. Current approach is to use the same amount of slag cement as used in earlier grout mix designs	At least 210 lbs of slag per cubic yard of reducing grout
High long-term strength of in-place grout	High long-term strength at any time is not required. The PA identifies a 2000 psi intruder barrier. This is also the minimum strength required for low permeability reducing grout.	At least 2500 psi at 90 days to meet 2000 psi req. for strong grout
Low long-term cracking	Minimize the potential for cracking: 1. Negligible early stage shrinkage 2. Negligible chemical incompatibility of materials 3. Negligible susceptibility to environmental corrodents 4. No cracking as the result of overburden loading 5. Seismic loading not considered	1. Use as much dimensionally stable sand and gravel as possible 2. Cracking mechanisms due to material incompatibility, phase changes, and corrodents were addressed elsewhere [Langton, 2007]. Continue with same materials unless new testing and research indicate potential for expansion. 3. Overburden loading is not an issue.
Low long-term degradation of the in-place grout	Durable: Perform design function over 100s to 1000s of years 1. Negligible cracking due to internal expansive reactions and external forces 2. Maintain chemical alkalinity and reducing chemistry	1. Chemical degradation is addressed elsewhere [Langton, 2007]. 2. Use equivalent or more portland cement (pH) and slag cement (Eh). Continue with same materials.
Adequate flowability of the grout during placement	Flow 35 feet in a tank with a 70 feet diameter from a central discharge point from a 2-10 foot free drop	Grout flow >11 inches per ASTM D 6103 Slump flow > 25 inches ASTM C 1611
Other Considerations		
Production	1. Suitable for on-site continuous or central mixer batch plant using locally available aggregate and simplify admixture additions if possible 2. Production Rate of at least 600 cubic yards/day 3. Pumpable 1500 feet	HRWR and VMA compatibility to enable addition as a slurry to support auger mixing.
Fresh Properties	1. High flow (grout) for slump-flow (3/8 inch aggregate) 2. Set time < 24 hours 3. Minimal bleed water (no bleed water is desirable) and segregation 4. Air entrainment not required for below grade placement 5. Cure under moist conditions 6. Low shrinkage	1. Slump-flow > 25 inches, grout flow 11-15 in. 2. Set time < 24 hours 3. Zero bleed after 24 hours 4. No air entrainment 5. High unit weight, low air content 6. Low paste content, moist cure, zero bleed
Cured Properties	1. 90 day strength ≥ 2 000 psi 2. Permeability < 2E-08 cm/sec (strong grout measurements) 3. Low Shrinkage 4. Heat of hydration suitable for mass pours	1. 90 day strength ≥ 2000 psi 2. Permeability < 2E-08 cm/sec (strong grout measurements 3. Portland cement + slag cement less than about 450 lbs/cubic yard.

2.0 EXPERIMENTAL METHODOLOGY

2.1 Ingredients

Grout mixes tested in this study were prepared with bulk materials obtained from local suppliers and chemical admixtures that are distributed nationwide. The Type I/II cement was manufactured by LaFarge, Inc. at their cement plant in Harleyville, SC. The Grade 100 slag cement was manufactured by Holcim, Inc., Birmingham, AL, and the fly ash was obtained from the Wateree Power Plant and supplied by SEFA, Inc. SRS process water was used as the mixing water. The ingredients are listed in Table 2-1. The aggregate properties are listed in Table 2-2.

Table 2-1. Ingredients Used to Prepare Samples of the FTF Closure Grouts.

Material	Specification	Supplier / Address	Phone Number
Portland cement (Type I/II)	ASTM C150	LaFarge, Cement Harleyville, SC obtained from Lafarge Ready Mix Augusta, GA	706-823-4471
Slag cement (Grade 100)	ASTM C987	Holcim, Inc. 3235 Satellite Blvd. Duluth, GA 30096	800-292-4355
Fly ash (Class F)	ASTM C618	Wateree Power Plant,* SC SEFA, Inc.	800-241-4943
Concrete sand	ASTM C33	SCMI Clearwater SC obtained from Lafarge Ready Mix, Jackson, SC	706-823-4471
No. 8 stone 3/8 inch gravel (granite)	ASTM C33	Martin Marietta Quarry Augusta, GA obtained from Lafarge Ready Mix, Jackson, SC	706-541-0187
HRWR			
Sika ViscoCrete 2100	ASTM C494 Type F	Sika Corporation	717-821-3721
*Hydration Stabilizer***			
Recover	ASTM C494 Type B	W.R. Grace & Co. 62 Whittemore Ave. Cambridge, MA 02140	617-876-1400
Viscosifier			
Kelco-Crete D® (Diutan Gum)		CP Kelco, Inc. 8355 Aero Dr. San Diego, CA 92123	858-292-4900
SRS domestic water		SRS	

* The fly ash used in the 2007 alternative all-in-one grout study came from Boral Materials technology, Inc., Atlanta, GA.
**Set Retarder and hydration stabilizers were not required for samples prepared under laboratory conditions.

Table 2-2. Size Distribution of the Sand and No. 8 Stone [Waymer, 2011].

Property	**Concrete Sand**		**No. 8 Aggregate (3/8 inch)**	
Bulk Unit Weight (lb/ft^3)	85 @ 1.6 wt. % SSD*		93 @ 0.6 wt. % SSD*	
Specific Gravity (particle)	2.65		2.56	
Composition	Quartz		Granite	
Moisture Content (as received)*	0.7 - 6.5 wt. %		~0	
Particle size Distribution +	Wt. % Passing	Cum. Wt. % Retained	Wt. % Passing	Cum. Wt. % Retained
½ inch (12.5 mm)	100	0	99.4	0.6
3/8 inch sieve	100	0	91.8	8.2
¼ inch sieve	--	--	40.0	60.0
#4 sieve (4.75mm)	99	1	14.2	85.8
#5 sieve (4.00 mm)	--	--	6.3	93.7
#8 sieve (2.36 mm)	96	4	0.6	99.4
#16 sieve (1.18 mm)	81	19	--	--
#30 sieve (600 μm)	50	50	--	--
#50 sieve (300 μm)	17	83	--	--
#100 sieve (150 μm)	2	98	--	--
Fineness Modulus	--	2.6	--	--

* Moisture content varied as a function of the storage time and conditions as determined by URS Quality and Testing Division personnel. ASTM C128 and ASTM C566 (total moisture). SSD = Surface Saturated Dry.
+ Percentage passing through each sieve as determined by ASTM C136.

2.2 Sample Preparation and Test Methods

Sample preparation and most testing were performed in the SRS Civil Engineering Test Laboratory which is operated by URS, Quality and Testing Division. The laboratory is located in N-Area. Samples were prepared according to ASTM C192 and cured in a constant temperature (73°F ±2°F) curing room at 100% relative humidity. A three cubic foot concrete mixer was used to prepare the grout mixes. See Figure 2-1. The batch size was typically 0.75 to 1.0 cubic feet.

The order of addition of ingredient to the mixer was as follows: gravel, sand, a portion of the water, fly ash, slag, cement and admixtures. The remainder of the water was added in total or in parts during the addition of the fly ash, slag, and cement. The mixing time was approximately five minutes after all of the ingredients were added. A sample was collected for the slump-flow measurement (Method ASTM C1161). After the test was completed, the material was returned to the mixer and mixed for another 5 minutes and additional HRWR or VAM was added if necessary. The batch was allowed to rest for another 5 minutes prior to measuring fresh properties. After the final slump-flow was measured, (See Figure 2-2a) the remaining material was used for unit weight, air content (See Figure 2-3), set time, and bleed water determinations; evaluation of flow under static conditions (modified ASTM D6103, Figure 2-2b); and to cast samples for strength, permeability and other hydraulic property measurements.

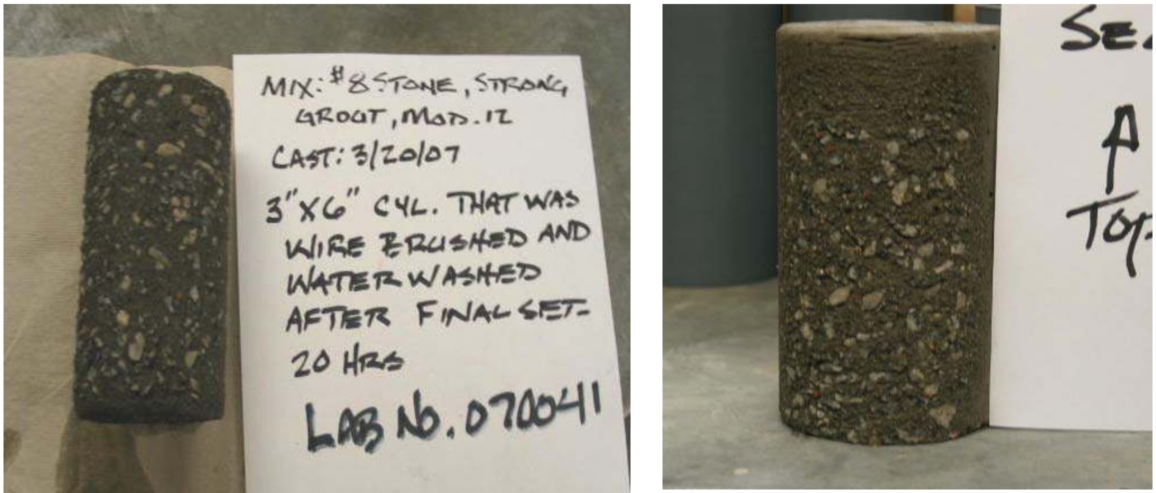
Three by six inch cylinders were cast for compressive strength measurements as a function of curing times (7, 28, and 90 days), and moisture retention characterization, i.e, volumetric water content as a function of head pressure (pressure plate test). Two by four inch samples were cast for hydraulic conductivity measurements at the URS laboratory (Method ASTM D5084 Method C). Three by six inch cylinders were cast for hydraulic conductivity measurements of selected samples performed at MACTEC (Method ASTM D5084 Method F).

Figure 2-1. Three cubic-foot concrete mixer used to prepare samples for grout formulation development.

(a) (b)

Figure 2-2. (a) ASTM C1611 Slump-Flow (25 inches) measurement and (b) Modified ASTM D6103 Flow under static conditions determination (12.5 inches for initial reading).

Figure 2-3. Air content test apparatus and including unit weight bucket.



(a) (b)

Figure 2-4. Visual Examination: (a) no segregation (b) significant segregation.

Figure 2-5. Hydraulic conductivity test apparatus and sample cells.

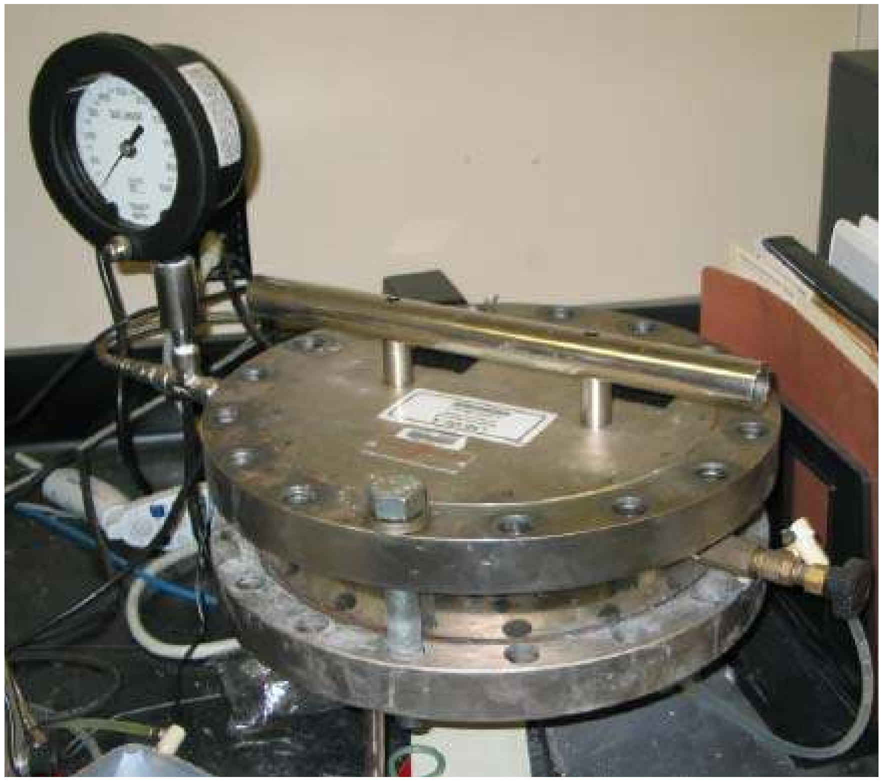


Figure 2-6. Pressure plate test configuration for moisture retention characterization.

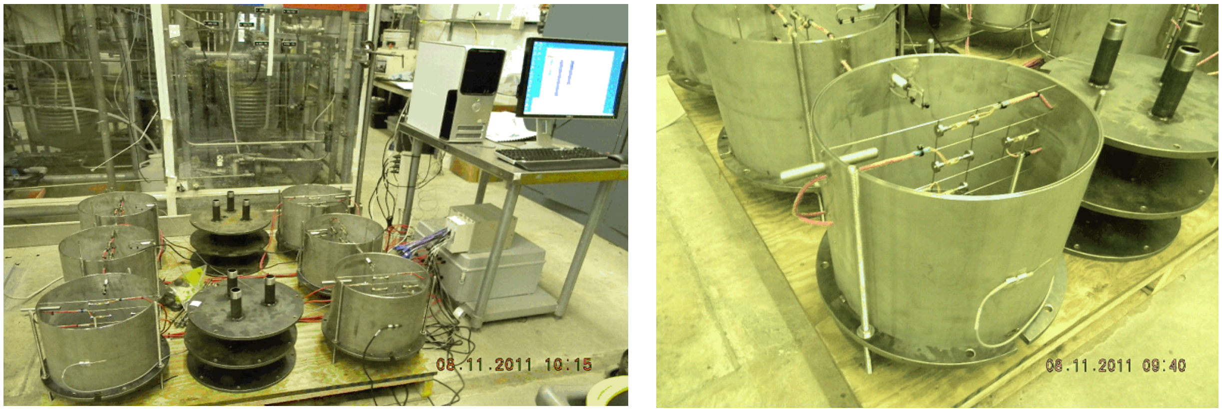
Test methods used for evaluating mix designs are listed in Table 2-3. A comprehensive list of the test methods used to characterize the recommended formulations including the test methods for measuring the hydraulic properties for the FTF PA are provide in a separate report [Stefanko and Langton, 2011].

Table 2-3. Test Methods Used to Determine Grout Properties.

Properties	ASTM Methods
Fresh Properties	
Flow (Initial and Static Flow)	D6103
Slump Flow	C1611
Set Time	UPV and visual
Bleed Water (24 hr.)	C232
Segregation*	Visual
Unit Weight	C138
Air Content	C231
Cured Properties	
Compressive Strength	C39
Saturated Hydraulic Conductivity	D5084 Methods C and F
Heat of Hydration	SRNL Adiabatic Calorimeter

* Segregation was measured by visual examination of a washed “green sample. See Figure 2-4. ASTM C1621 includes a method for quantifying segregation. The necessary test equipment has been acquired and will be used for future testing.

Special test forms were designed and instrumented to evaluate dimensional changes (shrinkage and expansion) as a function of time, temperature and humidity. These forms are shown in Figures 2-7 (a) and (b). Shrinkage and bonding to the steel forms for the selected mixes and for a shrinkage compensating mix was postponed by Tank Closure Project personnel.



(a) (b)

Figure 2-7. Shrinkage measurement forms and instrumentation.

3.0 RESULTS

Results for two flowable zero bleed structural fill concepts containing 3/8 inch gravel (70070 Series and LP#8 Series) and a sand only mix (SO Series) are provided in this report. Tank Farm Engineering and SRNL Project Management selected the 70070 mix as the base case for inclusion in Revision 0 of the Tanks 18-F and 19-F grout procurement specification [Forty, 2011 a] and requested admixture recommendations and property confirmation for this formulation. Lower cementitious paste mixes were formulated because the 70070 mix is over designed with respect to strength and generates more heat from hydration reactions than is desirable for mass pour application. Work was also initiated on a modification of the recommended mix which included shrinkage compensation to mitigate fast pathways caused by shrinkage cracking and poor physical bonding to the tank and ancillary equipment. Testing of this option was postponed.

3.1 Mix 70070 and Modification

Tank Farm Engineering and SRNL project management personnel selected Mix 70070 from an earlier report [Langton, et. al, 2007] and requested that the admixtures for this mix be updated so it could be incorporated in the 2011 specification for tank closure grout as a base case formulation [Jolly, 2011]. Currently available admixtures were identified and proportioned to achieve fresh properties (ASTM C1611 slump flow) comparable to those in the 2007 report. Results for the original 70070 mix design and mix 70070 with new admixtures are provided in Table 3-1.

The 70070 mix contains a large amount of paste (cement plus slag plus fly ash) and has relatively low water to cementitious materials ratio, 0.391. Both of these features contribute to two issues that make selection of this grout for closing Tanks 18-F and 19-F problematic: 1) high heat of hydration and 2) high viscosity of the paste fraction which can be interpreted as requiring a longer time for the grout to spread in the tank.[3] Although the ASTM C1611 flow and compressive strength are excellent (> 28 inches), this type of mix is very cohesive. Consequently it will take longer to spread out in the tank than a mix with a lower viscosity which can be achieved with a higher water to cementitious materials ratio and / or less paste.

Given the project decision to use an off-site supplier to batch the tank fill grout and deliver it by truck to the F-Tank Farm, logistical issues which disrupt a steady discharge into the tanks were assumed to be likely. Disruptions in flow will reduce the amount of spread in the tank especially for a high viscosity cohesive mix like 70070. To increase grout flow / spreading under these conditions, a series of modified 70070 trial mixes were designed and tested.

These mix proportions and properties are also provided in Table 3-1. Mixes containing a range of cement contents, 185, 150, 125, and 100 pounds per cubic yard and a lower slag content 210 rather than 260 pounds per cubic yard were tested. All of the mixes in this series had a high paste content. The amount of reactive material was reduced and replaced with an equivalent volume of fly ash and / or water. Consequently, the heat of hydration was lowered, but the rheology was not significantly improved. The flow according to ASTM C1611 was excellent for all of the mixes. However, all of the mixes in this series were very cohesive. Some mixes were described as sticky and were especially difficult to scrape off of the flow board a few minutes after completion of the test. This feature is undesirable when flow and self-leveling in a tank 85 feet in diameter are required. Consequently this series was not recommended for closing Tanks 18-F and 19-F.

[3] The high amount of solids per unite volume and the high solids to water ratio results in a mix with a higher apparent viscosity relative to other mixes tested.

Table 3-1. Ingredients, Proportions and Properties for the FTF 70070 Series of Tank Fill Grout Trial Mixes.

FTF 70070 Series Ingredient (lbs/cyd)	**211 Spec Rev.0 (from WSRC-STI-2007-00641)**	**Modified 2011 Spec Rev. 0 w/ new Admixtures**	**Mod 8**	**Mod 4**	**Mod 7**	**Mod 6b**	**Mod 6c**	**Mod 5**	**Mod 5b**	**Mod 1**	**Mod 2**	**Mod 3**
w/cm_{total}	**0.391**	**0.391**	**0.391**	**0.391**	**0.391**	**0.391**	**0.391**	**0.391**	**0.391**	**0.412**	**0.412**	**0.412**
Portland Cement, Type I/II	**185**	**185**	**125**	**185**	**150**	**125**	**125**	**100**	**100**	**185**	**185**	185
Slag Cement Grade 100	**260**	**260**	**260**	**210**	**210**	**210**	**210**	**210**	**210**	**260**	**260**	260
Fly Ash, Class F	850	850	892	887	912	930	930	947	947	740	720	720
Concrete Sand, Quartz	942	942	865	859	865	868	868	871	871	942	1040	1040
Gravel, No. 8 Stone 3/8in. crushed granite	946	946	860	861	865	870	870	874	874	946	946	946
Water (lb/cyd) (gallons/cyd)	506 60.7	506 60.7	491.1 59.0	500.9 60.1	497.0 59.7	494.2 59.3	494.2 59.3	491.1 59.0	491.1 59.0	506 60.7	480 57.6	480 57.6
HRWR SIKA ViscoCrete 2100 (fl oz/cyd)	54 Advaflex	41 Sika 2100	40.5	40.5	29	41	30	40.5	27	27	27	27
VMA, Kelco CP, Diutan Gum (g/cyd)	216 Welan Gum	162 Diutan Gum	162	162	122	162	162	162	162	108	108	162
Fresh Properties												
Slump Flow, ASTM C1611 (in.)	31.5	30.5	28.75	31	29.25	34.5	28	36	28	31	26	24
Spread, ASTM D-6103 (in.) Static time after mixing (min)	t_0 = 12.5	t_0 = 13.0 t_{55} = 7.5	t_0 = 13.75 t_{57} = 0	t_0 = 13.5 t_{38} = 6.5	t_0 = 14.25 t_{30} = 0	NM	t_0 = 13.75 t_{30} = 8.0	t_0 = 16.5 t_{35} = 14	t_0 = 12.25 t_{30} = 5.75	NM	t_0 = 9	t_0 = 10.0 t_{30} = 9.0
Air Content (vol. %)	1.7	0.9	1.5	1.6	1.5	1.5	1.8	1.3	2.1	0.8	1.6	1.9
Set Time (hr.)	< 24	<20.5	<20	<20.5	<16	NM	<15	<16	<15	<18	<18	<24
Bleed (ml)	0	7 ml (10 h) 0 ml (24 hr)	0	0	0	NM	0	0	0	124	29	11
Unit Weight (lbs/cft)	132.3	129.72	127.64	127.72	129.44	130.45	129.44	127.84	127.03	129.85	132.66	131.38
Cured Properties												
Compressive Strength (psi)												
7 days	NM	820	870	740	460	NM	590	610	560	890	780	790
28 days	3440	4185	3750	3715	3185	NM	3135	2920	2915	4235	3735	3780
90 days	4840	6005	4975	6110	4585	NM	4205	4235	3920	5875	5525	5855
180 days	5970	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Sat. Hydraulic Conductivity $k_{hsat@20}$ ASTM D5084 Method C (cm/s)	6.60E-09	5.5E-09	4.2E-09	2.8E-09	3.7E-09	NM	2.2E-09	5.5E-09	TBD	2.4E-09	2.0E-09	4.6E-09
Shrinkage (%)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Settlement	NM	small amount	none	small amount	none	some	none	considerable	none	NM	NM	NM
Adiabatic Temperature Rise (°C)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	44.7
Maximum Calorimeter Temperature for starting temperature 24 °C (°C)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	T_i = 24 T_f = 54.2
Date prepared		6/1/2011	6/9/2011	6/1/2011	6/8/2011	6/8/2011	6/8/2011	6/1/2011	6/1/2011	4/5/2011	4/5/2011	4/6/2011
Comments	NM	NM	NM	NM	NM	NM	sticky	NM	sticky	NM	sticky	sticky

3.2 Sand Only All-In-One Mix Series

A second base case mix, a sand only all-in-one zero bleed reducing grout, OPCEXE-X-P-O-BS, which was included in a 2007 draft tank fill grout specification, C-SPP-F-00047 Rev 2, was also evaluated. The properties of this mix were used in the current FTF PA [SRS, 2007]. New admixture doses were identified for this mix and modifications were made to this mix to increase the 28 day strength (> 2000 psi). The water to cementitious materials ratio which is relatively high, 0.757 was decreased and more cement was added. An equivalent volume of fly ash was removed to account for the additional cement. The proportions and properties of the sand only (SO) all-in-one mixes with the new admixture doses are listed in Table 3-2.

Increasing the amount of cement in the modified mixes from 100 to 185 pounds per cubic yard had a larger effect on the 90 day strengths than on the 28 day strengths. Decreasing the water to cementitious ratio by 0.05 (from 0.757 to 0.707) also consistently increased the 90 day compressive strengths by at least 300 psi for the formulations tested. The SO series of mixes were flowable after standing for 30 minutes under static conditions. Consequently, even though the ASTM C1611 flows were not as large as mixes with gravel, this mix concept is suitable for filling tanks that require flow over 45 ft.

Full scale mock up testing of this type of mix is not a high priority because a similar mix was used as the bulk fill for Tanks 17-F and 20-F. However, during the Tank 17-F and 20-F closure, admixture adjustments during on-site production were required to keep the production grout flowable. Such adjustments would add extra steps and testing to preparing and trucking grout from off site or adjusting admixtures in the truck at the point of delivery.

3.3 LP#8 Series

The first alternative grout designed for filling Tanks 18-F and 19-F was based on previous experience in designing robust self-leveling, flowable structural fills for in-situ decommissioning 105 P- and R-Reactor facilities during 2010 and 2011. The ingredients, proportions, and properties for the grout used to fill the bulk of the below grade portions of these structures are listed in Table 3-3. The reactor grout did not meet the chemical requirements (no slag) and all of the cured property requirements (compressive strength) for tank closure. However, it had excellent flow, self leveling, and zero bleed characteristics. Consequently, this mix concept was modified by adding slag, adjusting the cement content, and lowering the water to cementitious materials ratios from 0.641 to a range between 0.610 and 0.500. This series of mixes is referred to as the LP#8 Series (low paste with No. 8 stone).

This mix concept is robust. Mixes with water to cementitious materials ratios between 0.610 and 0.500 met the flow requirements. All of the mixes with as little as 100 pounds of Portland cement plus 210 pounds of Grade 100 slag per cubic yards met the strength requirements. Consequently, this mix concept is best suited for the tank closure fill grout. Mix LP#8-16 was recommended for Tank 18-F and 19-F grout specification based on data collected to date [Langton and Stefanko, 2011]. Pending permeability results, a mix with a lower water to cementitious materials ratio, LP#8-20 was also recommended as an alternative.

Table 3-2. Ingredients, Proportions and Properties for the Sand Only (SO) Series of Tank Fill Grout Trial Mixes

SO Series	All-In-One (new admix) w/cm = 0.757 WSRC-STI-2007-00641	SO Series 1: w/cm_{total} = 0.757					SO Series 2: w/cm_{total} = 0.707				0.657	0.682
Ingredient (Lb/cyd) Mix No.	**SO-001b**	**2**	**3**	**3b**	**4**	**5b**	**6b**	**7**	**8**	**9**	**10**	**10b**
Portland Cement, Type I/II	75	100	125	125	150	185	100	125	150	185	100	100
Slag Cement Grade 100	210	210	210	210	210	210	210	210	210	210	210	210
Fly Ash, Class F	375	357	340	340	322	297	357	340	322	297	357	357
Concrete Sand, Quartz	2300	2355	2337	2337	2323	2303	2442	2425	2413	2395	2530	2486
Gravel, No. 8 Stone,	0	0	0	0	0	0	0	0	0	0	0	0
Water (lb/cyd) (gallons/cyd)	499.6 60	504.9 60.6	511.0 1.3	511.0 61.3	516.30 62.0	523.8 62.9	471.6 56.6	477.2 57.3	482.2 57.9	489.2 58.7	438.2 52.6	454.9 54.6
HRWR SIKA ViscoCrete 2100 (fl oz/cyd)	27	27	27	41	27	36	45	50	45	45	72	72
VMA, Kelco CP, Diutan Gum (g/cyd)	169.92	170.64	169.92	170	169.92	169.92	135	135	135	135	*81*	135
Fresh Properties												
Slump Flow, ASTM C1611(in.)	25	24.5	23.75	25	22.75	25.63	23.25	23.75	24.13	23.5	16.75	20.5
Spread, ASTM D-6103 (in.) after mixing and after static period (min)	t_0= 10.0 t_{30}= 9.0	t_0= 10.0 t_{30}= 9.25	t_0= 10.5 t_{30}= 6.0	t_0= 11.25 t_{30}= 10.5	t_0= 11.62 t_{30}= 4.75	t_0= 12.5 t_{30}= 8.0	t_0= 10.0 t_{30}= 11.25	t_0= 10.5 t_{30}= 9.75	t_0= 10.0 t_{30}= 9.25	t_0= 9.75 t_{30}= 7.75	t_0= 5.75 t_{30}= 6.0	t_0= 8.0 t_{30}= 6.0
Air Content (vol. %)	3.6	3.3	3.5	3.3	3.8	2.0	4.0	2.8	3.1	3.1	5.5	5
Set Time (hr.)	<24	<24	<20	<13	<19	<15	<18	<17	<16	<15	NM	<24
Bleed (ml)	0	0	0	0	0	0	0	0	0	0	8	0
Unit Weight (lbs/cft)	126.63	127.43	126.43	126.03	126.23	128.24	127.64	129.44	128.24	128.64	127.2	127
Cured Properties												
Compressive Strength (psi)												
7 days	270	210	230	280	260	310	260	300	320	400	NM	340
28 days	1790	1810	1770	1820	1960	2055	1880	2105	2120	2270	NM	2030
90 days	3530	3020	3450	3380	3730	3875	3465	4085	4160	4415	NM	3285
Sat. Hydraulic Conductivity $k_{hsat@20}$ ASTM D5084 Method C (cm/s)	6.3E-09	2.4E-09	1.2E-09	2.0E-09	4.5E-09	2.4E-09	3.0E-09	2.1E-09	2.2E-09	3.0E-09	NM	3.1E-09
Shrinkage (%)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Adiabatic Temperature Rise (°C)	27.2	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Maximum Temperature given starting temperature of 24°C (°C)	T_i = 24 T_f= 42.2	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Date prepared	5/19/2011	5/19/2011	5/24/2011	5/31/2011	5/24/2011	5/24/2011	5/25/2011	5/25/2011	5/25/2011	5/25/2011	5/26/2011	5/26/2011

Table 3-3. Ingredients, Proportions and Properties for Low Paste with No. 8 Stone (LP#8) Series of Tank Fill Grout Trial Mixes.

LP#8 Series	Reactor Fill w/cm = 0.641	LP#8 Series 1: w/cm$_{total}$ = 0.610				LP#8 Series 2: w/cm$_{total}$ = 0.580				LP#8 Series 3: w/cm$_{total}$ = 0.550				LP#8 Series 4: w/cm$_{total}$ = 0.500			
Ingredient (Lb/cyd)		**12**	**14**	**11**	**13**	**15**	**16**	**17**	**18**	**19b**	**20**	**21**	**22**	**25**	**23**	**24**	**26**
Portland Cement, Type I/II	150	100	125	150	185	100	125	150	185	100	125	150	185	100	125	150	185
Slag Cement Grade 100	0	210	210	210	210	210	210	210	210	210	210	210	210	260	260	260	260
Fly Ash, Class F	500	380	363	345	320	380	363	345	320	380	363	345	320	418	400	383	358
Concrete Sand, Quartz	1850	1750	1735	1750	1708	1805	1790	1778	1765	1860	1847	1837	1822	1635	1630	1621	1613
Gravel, No. 8 3/8 inch Crushed Granite	800	800	800	800	800	800	800	800	800	800	800	800	800	973	970	965	960
Water (lb/cyd) (gallons/cyd)	416.5 50.0	420.9 50.5	425.8 51.1	430.0 50.5	436.2 52.4	400.2 48.0	404.8 48.6	408.9 49.1	414.7 49.8	379.5 45.6	383.90 46.1	387.8 46.5	393.3 47.2	387.8 46.5	392.5 47.1	396.5 47.6	401.5 48.2
HRWR SIKA ViscoCrete 2100 (fl oz/cyd)	79	49.5	45	36	49.5	40.5	40.5	40.5	40.5	54	54	45	54	45	45	54	45
VMA, Kelco CP, Diutan Gum (g/cyd)	205	200.16	200.16	199.8	200.16	200.16	200.16	200.16	200.16	120.24	155.16	119.16	120.24	162	162	162	162
Fresh Properties																	
Slump Flow, ASTM C1611 (in.)	24 ± 4	25.75	28.25	26	28	27.5	25.75	27	25	25	24.5	25.25	27	26	25.25	26	24
Air Content (vol. %)	< 8	1.5	1.3	1.6	1.5	1.2	2	1.5	2.2	2.8	2.5	2.1	NM	1.7	1.6	1.6	1.7
Set Time (hr.)	< 24	< 24	< 24	< 24	< 24	< 24	< 18	< 18	< 18	< 20	< 24	< 24	< 24	< 19	< 19	< 20	< 17
Bleed (ml)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unit Weight (lbs/cft)	NA	134.94	133.9	132.86	134.94	133.33	133.67	132.26	134.27	133.67	132.86	133.67	132.86	136.68	136.68	137.89	137.89
Spread, ASTM D-6103 (in.) after static period (min)	NM	NM	NM	NM	NM	NM	t_{30} = 9.5 in.	NM	NM	NM	t_{30} = 9 in.	NM	NM	t_0 = 12.5 t_{35} = 12.5	t_0 = 11. 5 t_{36}= 10.75	t_0= 11.75 t_{32}= 11.5	t_0= 10.5 t_{40}= 7.5
Cured Properties																	
Compressive Strength (psi)																	
7 days (1)	~250	340	190	410	280	160	370	360	490	360	360	480	590	970	970	950	1010
28 days (2)	~780	2335	2575	2500	3045	2300	2680	2495	2940	2560	2465	3090	3110	3780	4145	4585	5155
90 days	~1640	3815	4595	4185	5040	3705	4560	4530	5270	4060	4395	5205	5100	5020	5830	6855	7280
Sat. Hydraulic Conductivity $k_{hsat@20}$ ASTM D5084 Method C, URS Data (cm/s)	1.30E-08	NM	NM	3.2E-09	NM	3.1E-09	2.1E-09	2.4E-09	NM	2.5E-09	See Section 3.5	4.2E-09	2.0E-09	2.1E-09	1.1E-09	2.0E-09	.3.E-09
Shrinkage (%)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Porosity	NM	NM	NM	NM	NM	NM	0.21	NM	NM	NM	0.21	NM	NM	NM	NM	NM	NM
Settlement/segregation	NM	NM	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Adiabatic Temperature Rise (°C)	< 25	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	41	NM	NM	NM	37.2	NM
Maximum Temperature for starting temperature of (°C)	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	T_i = 22.0 T_f= 49.9	NM	NM	NM	T_i = 25.0 T_f= 51.5	NM
Date prepared		5/12/2011	5/12/2011	5/11/2011	5/12/2011	5/12/2011	5/16/2011	5/16/2011	5/16/2011	5/16/2011	5/17/2011	5/17/2011	5/17/2011	6/14/2011	6/9/2011	6/14/2011	6/14/2011

3.4 Thermal Property Characterization for Selected Mixes

Adiabatic calorimetry was used to measure heats of hydration and adiabatic temperature increases for different grout compositions and was documented in a previous report [Steimke and Fowley, 1997]. Freshly mixed grout was placed in a stainless steel dewar which was placed inside a stirred bath of ethylene glycol. Half of a calibrated differential thermocouple was placed in the middle of the grout and the other half was placed in the bath. The calorimeter was programmed to add just enough heat to the bath to exactly match the temperatures of grout and bath. Because there was no temperature difference, no heat flowed in or out of the grout, which means adiabatic conditions.

Most of the heat generated by the hydrating grout was consumed in increasing the temperature of the grout, but some heat went to heating the thin plastic sleeve in the dewar, the inner surface of the dewar and the inner half of the rubber stopper in the dewar. The relationship for total heat generation rate in watts is provided below: where M and Cp are the masses and heat capacities of the grout and the other three components that absorb heat, respectively, and T_c is the grout temperature in the calorimeter [Steimke and Fowley, 1997].

Equation 1.

$$G = \frac{dT_c}{dt}\sum_{i=1}^{4} M_i C_{pi}$$

The total heat generated in joules is calculated by integrating Equation 1.

Equation 2.

$$\Delta H = \Delta T_c \sum_{i=1}^{4} M_i C_{pi}$$

Rearranging Equation 2 for calorimeter temperature increase gives the following equation:

Equation 3.

$$\Delta T_c = \frac{\Delta H}{\sum_{i=1}^{4} M_i C_{pi}}$$

For a massive pour of grout where the heat generated is consumed only by grout and not other objects in the experiment, the Equation 3 reduces to the following for adiabatic temperature increase where the subscript g refers to grout.

Equation 4.

$$\Delta T_a = \frac{\Delta H}{M_g C_{pg}}$$

Solving Equation 3 for ΔH and substituting in Equation 4 gives the equation for adiabatic temperature increase for a large pour of grout.

Equation 5.

$$\Delta T_a = \Delta T_c \frac{\sum_{i=1}^{4} M_i C_{pi}}{M_g C_{pg}}$$

Adiabatic calorimeter data for selected grouts are provided in Figures 3-1 and 3-2. A summary of the thermal properties including the adiabatic temperature rise for complete hydration and density are provided for selected mixes in Table 3-4.

The number of samples for which the adiabatic temperature rise was measured was limited due to the cost of these analyses. However, method of calculating temperature rise as a function of composition is being developed by SRNL / EDL personnel. The other thermal properties, i.e., specific heat and thermal conductivity, do not vary very much between samples within a mix series which supports using an estimated value in thermal transient calculations.

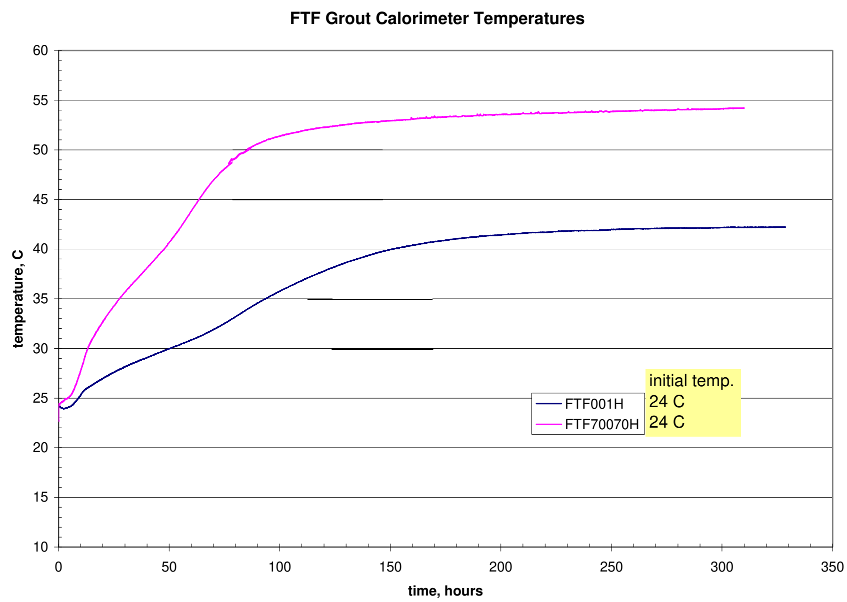


Figure 3-1. Adiabatic calorimeter data for Mixes FTF001H and FTF70070H.

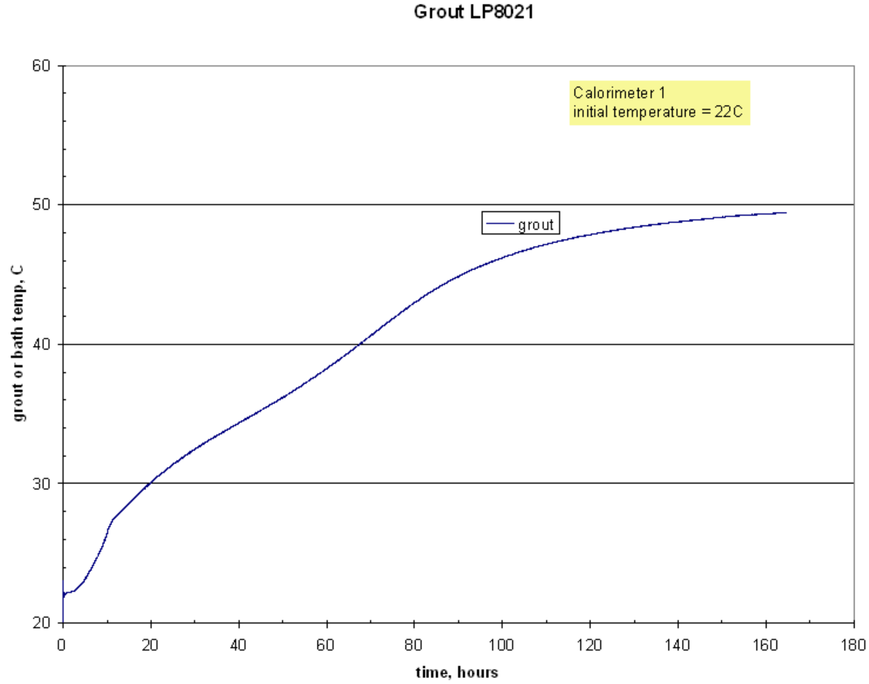


Figure 3-2. Adiabatic calorimeter data for Mix LP#8-021H.

Table 3-4. Summary of thermal properties for representative mixes.

Thermal Property	FTF70070H	All-In-One FTF-SO-001H	LP#8-016	LP#8-020	LP#8-021H	LP#8-024H
Cement (lbs/cyd)	185	75	125	125	150	150
Slag (lbs/cyd)	260	210	210	210	210	260
Adiabatic Temperature Rise for complete hydration (°C)	44.7	27.2	34*	34*	41.0	37.2
Density (g/cm^3)	2.115	2.076	2.21*	2.21*	2.208	2.213
Specific Heat (cal/g-K)	0.29	0.284	0.26*	0.26*	0.259	0.296
Specific Heat (J/kg-K)	1214	1189	1080*	1080*	1082	1240
Thermal Conductivity (W/m-K)	2	2.5	2.5*	2.5*	2.45	2.45
Thermal Conductivity, J/mL	115	67	85*	85*	98	102

* Estimated

The maximum temperature of the mix was calculated by adding the adiabatic temperature rise to the starting temperature which in the experiments ranged from 22 to 24°C. Under field conditions, the starting temperature of the grout ingredients can be 30°C or higher. For a maximum grout temperature of 65°C, the adiabatic temperature rise needs to be less than 35°C for starting materials that have an average temperature of 30°C (86°F).

3.5 Performance Assessment Hydraulic Property for Selected Mixes

Saturated hydraulic conductivity was measured for select samples in the URS laboratory (ASTM D5084 Method C) and also at MACTEC, Atlanta GA.[4] MACTEC used ASTM D5084 Method F and also characterized the moisture retention (drainage) as a function of saturation. MACTEC data sheets are provided in Attachment 1.

Table 3-5. Hydraulic properties for the grouts recommended for closing Tanks 18-F and 19-F.

	Saturated Hydraulic Conductivity K_s at 20° (cm/s)	Saturated Hydraulic Conductivity K_s at 20° (cm/s)	Saturated Hydraulic Conductivity K_s at 20° (cm/yr)	Saturated Effective Diffusion Coefficient (cm^2/s)	Saturated Effective Diffusion Coefficient, D_e (cm^2/yr)	Effective Porosity (%)	Dry Bulk Density (g/cm^3)	Average Particle Density (g/cm^3)	Moisture Content (Average) (wt %)
Material	URS Method C	MACTEC Method F	MACTEC Method F	FTF PA	FTF PA	MACTEC	MACTEC	Calcu-lation	MACTEC
LP#8-16	2.1E-09	3.1E-10 average of 3 samples	9.78E-03	5.0E-08 literature	1.58E+00 literature	0.21	1.97	2.49	24.3
LP#8-20	Not Measured	3.5E-10 average of 3 samples	1.10E-02	5.0E-08 literature	1.58E+00 literature	0.21	1.98	2.51	21.7

Results for the moisture retention as a function of applied pressure (pressure plate test) are summarized in Table 3-6 for pressures between 0 and 15 bars. MACTEC data sheets are provided in Attachment 1. Samples were submitted to K. Dixon, SRNL, for moisture retention measurements over the range 15 to 45 bars but results are not available at this time. The intent is to combine both sets of results to calculate the relative hydraulic conductivity (hydraulic conductivity as a function of saturation) according to the protocol identified in SRNL-RP-2011-00977 [Stefanko and Langton, 2011]. The moisture retention data are reported as volumetric water content as a function of head pressure and are used as input to the RETC Code which is used to calculate relative hydraulic conductivity for input into the PORFLOW code. PORFLOW is the reactive transport code used for the FTF Performance Analysis.

Table 3-6. Moisture retention as a function of applied pressure for LP#8-016 and LP#8-020.

Sample No.	**Initial moisture content**	**Dry unit weight**	**Applied Pressure (bars)**					
			0.10	**0.50**	**1.0**	**5.0**	**10.0**	**15.0**
	(vol %)	**(lb/cft)**	**Retained Water (volume percent)**					
LP#8-016A (average of 2)	24.3	127.0	24.1	24.0	23.8	23.6	23.2	23.0
LP#8-020A (average of 2)	21.65	121.5	21.2	21.1	21.0	20.7	20.4	20.1

4 MACTEC was recently acquired by amec, Inc.

4.0 DISCUSSION

The LP#8 Series structural flowable fills with water to cementitious materials of 0.550 to 0.580 were down selected as candidates for filling Tanks 18-F and 19-F based on fresh properties, compressive strength at 28 days, and formulation robustness with respect to water and cement contents. The LP#8 series of trial mixes were designed to be zero bleed, flowable structural fill grouts that contained 800 lbs/cyd of the 3/8 inch granite gravel. Benefits of including 3/8 inch pea gravel (No. 8 Stone) rather than using concrete sand as the only aggregate include: better mixing and homogeneity, better flows and compressive strengths as a function of water to cementitious material ratios.

4.1 Compressive Strength

All of the mixes in the LP#8 series with water to cementitious materials ratios of 0.580 and 0.550 met the compressive strength requirement of 2000 psi at 28 days[5] identified in Technical Task Request HLE-TTR-2011-008 [Chander, 2011]. All of the mixes for which data has been collected exceed the requirement of 2000 psi by a factor of 2 (i.e., 4000 psi) after curing for 90 days. See Figures 4-1 and 4-2. 100 to 125 lbs of Portland cement and 210 pounds of Grade 100 ground granulated blast furnace slag are sufficient to meet the strength requirement.

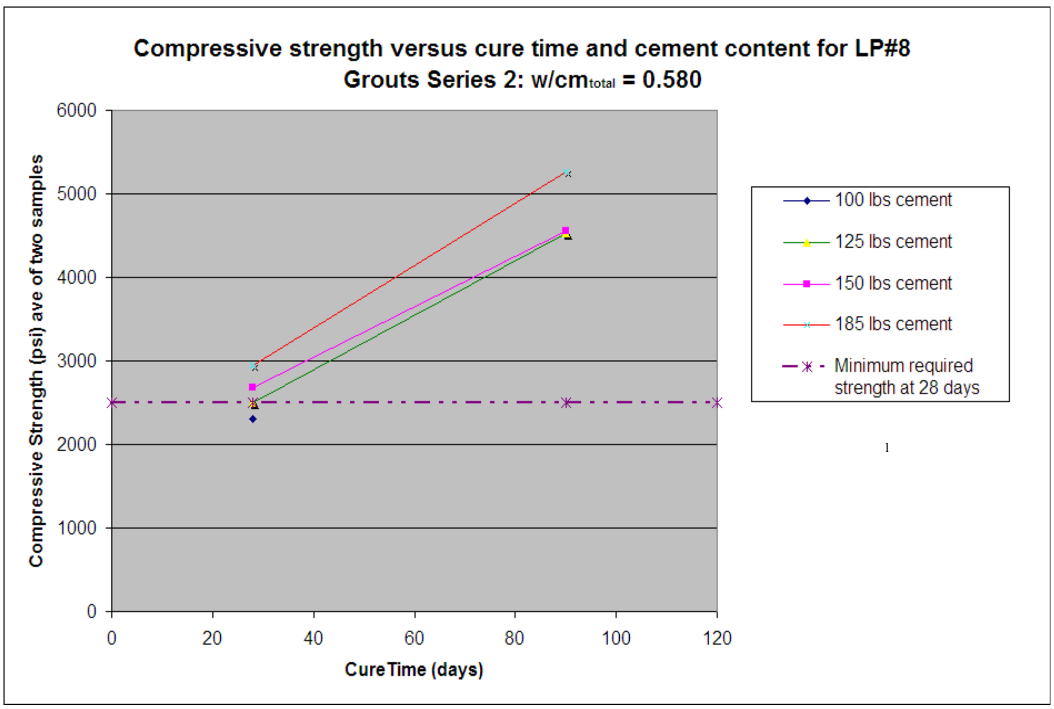


Figure 4-1. Compressive Strength versus cure time for LP#8 Grout Series 2 mixes with different cement contents and water to cementitious material ratio of 0.580.

[5] The basis for the 2000 psi at 28 days compressive strength requirement is the FTF PA. The functional basis of this compressive strength requirement is that the all-in-one grout must serve as an intruder barrier which requires a minimum strength of 2000 psi. The design requirement for compressive strength was 2500 psi to insure that the 2000 psi requirement is met for test cylinders evaluated during full-scale production. This assumes curing at 100 % relative humidity, 73° ± 3°F [Langton, 2011].

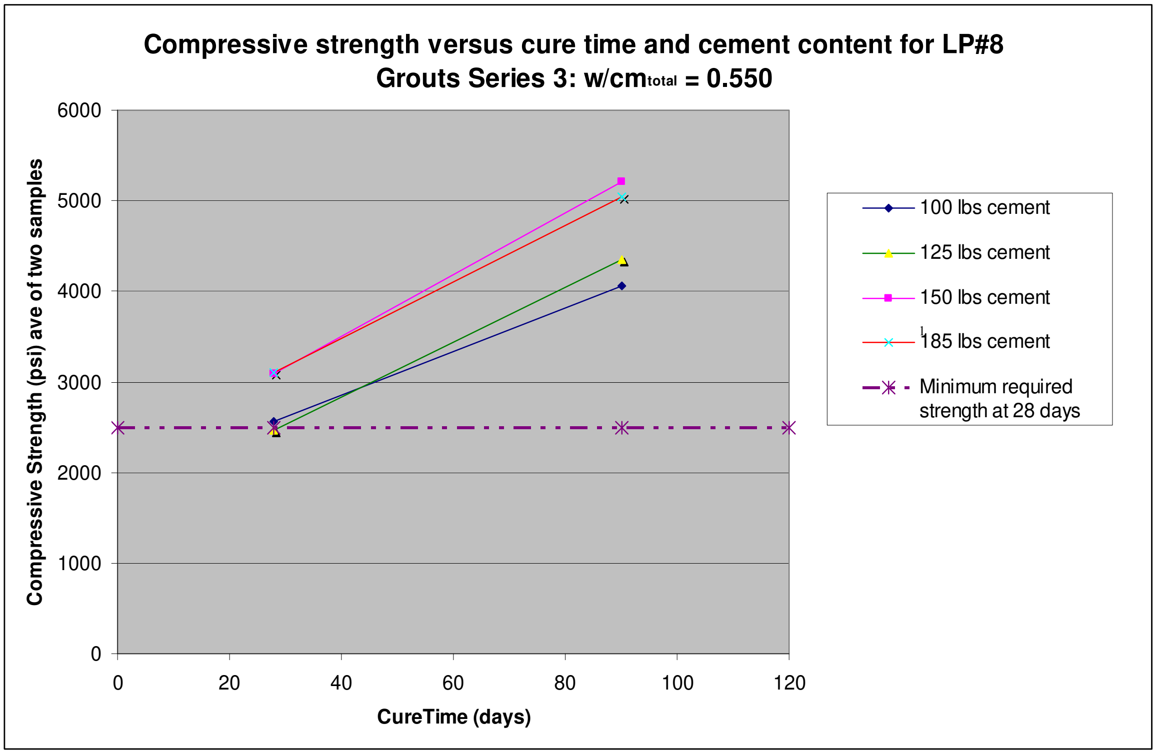


Figure 4-2. Compressive Strength versus cure time for LP#8 Grout Series 2 mixes with different cement contents and water to cementitious material ratio of 0.550.

4.2 Heat of Hydration

Further down selection was based on limited adiabatic temperature rise data and hydraulic conductivity data. Since limited adiabatic temperature rise data were available, information was compiled for all tank fill trial mixes tested. These results were compiled as a function of cementitious material proportions. The mixes had Portland cement contents between 75 and 185 pounds per cubic yard and slag contents of 210 and 260 pounds per cubic yard. Fly ash was not used in the comparison because the mixes do not have enough free calcium ion, i.e., $Ca(OH)_2$ to react with all of the fly ash. The unreacted fly ash serves the function of an inert filler.

Mixes with 150 lbs/cyd cement and 260 lbs/cyd slag exceeded the maximum allowable temperature of 65°C as identified in the TTR for curing under adiabatic conditions [Chander, 2011]. Assuming an ambient temperature of 35°C (95°F), trial mixes with 150 lbs/cyd cement and 260 lbs/cyd exceed the requirement of < 65°C, e.g., 37.2°C + 35°C = 72.2°C. A trial mix containing 75 lbs/cyd cement and 210 lbs/cyd met the requirement of < 65°C, e.g., 27.2°C + 35°C = 62.2°C.

It should be recognized that the tank fill conditions will not be truly adiabatic and that the calculated adiabatic temperature rise values presented in Table 4-1 assume complete reaction of 100 percent of the cement, slag, and fly ash. However, reducing the amount of cement and slag is justified because strength gain, i.e. hydration reactions are documented to occur over at least 90 days and result in more than doubling the strength measured for samples cured for 28 days. See Figure 4-1.

Table 4-1. Adiabatic Temperature Rise Data for Selected Candidate Tank Fill Grout Trial Mixes.

Mix Number	Cement (lb/cyd)	Slag (lb/cyd)	Fly ash (lb/cyd)	Run Time (hr)	Start Temp (°C)	End Temp (°C)	Run ΔTemp (°C)	Calculated Adiabatic Temp Rise (°C)
FTF001H	75	210	375	330	24	42.5	18.7	27.2
LP#8-016	125	210	363	Not measured	Not measured	Not measured	Not measured	34*
LP#8-020	125	210	363	Not measured	Not measured	Not measured	Not measured	34*
LP#8-021	150	210	345	168	22	49.9	27.9	41.0
LP#8-024	150	260	383	260	25	51.5	26.5	37.2
FTF 70070 mod 3H	185	260	720	310	24	54	30.7	44.7

* Estimated

The adiabatic calorimeter temperature rise for the mix recommended for closing Tank 18-F and 19-F was estimated rather measurements were not performed on the mix recommended for closing Tank 18-F and 19-F.

4.3 Hydraulic Conductivity

Further down selection was based on hydraulic conductivity values for selected mixes. Since limited data were available at the time this report was drafted, all information available for the LP#8 Series mixes and related Reactor Fill Grout was compiled. All of the trial mixes tested met the saturated hydraulic conductivity requirement of < 3.6 E-08 cm/s for samples cured at least 44 days [Chander, 2011].

Saturated hydraulic conductivity results are presented in Table 4-2. The URS results were determined by ASTM D5084 Method C whereas the MACTEC results were determined by ASTM D5084 Method F. The lower pressure used in Method C produced less than values in the time of the measurement. Data provided by MACTEC are included in Attachment 1.

Table 4-2. Saturated Hydraulic Conductivities for Selected Candidate Tank Fill Grout Mixes.

Mix Number	Cement (lb/cyd)	Slag (lb/cyd)	Fly ash (lb/cyd)	Cure Time (days)	W/CM_{total}	URS Hydraulic Conductivity $K_{h@20°C}$ (cm/s)	MACTEC Hydraulic Conductivity $K_{h@20°C}$ (cm/s)
Reactor Fill Grout	150	0	600	> 180	0.641	1.3E-08	Not measured
LP#8-016	125	210	363	70	0.580	2.1E-09	3.1E-10
LP#8-020	125	210	363	70	0.550	Not measured	3.5E-10
LP#8-021	150	210	345	62	0.550	4.2E-09	Not measured
LP#8-025	100	260	418	44	0.500	< 2.10E-09	Not measured

5.0 CONCLUSIONS AND RECOMMENDATIONS

The cement and slag contents of the mix selected for filling Tanks 18-F and 19-F should be limited to no more than 125 and 210 lbs/cyd, respectively, to account for heat generated as the result of hydration reaction during curing over extended times (> 90 days). Trial mixes with water to total cementitious materials ratios of 0.550 to 0.580 and 125 and 210 lbs/cyd cement and slag, respectively, met the strength and permeability requirements.

Mix LP#8-16 is recommended for scale-up testing to confirm suitability for the purpose of filling / closing Tanks 18-F and 19-F.[6]

Full-scale batching of the recommended mix should be performed in order to confirm scale-up in support of the procurement specification. The following items should be considered to validate the recommended mix:

- Batch at least 4 cubic yards of each material by a commercial batch plant and delivering the material to SRS. (4 cubic yards is about the minimum that can be batched and delivered in a 9 or 10 cubic yard concrete truck to provide a representative mixing and transport conditions.)
- Measure semi-adiabatic heat generation for a one cubic yard insulated pour.
- Evaluate fresh properties as a function of time (travel time and hold up time) after cement is added to the mixes.
- Evaluate cured properties.
- Evaluate flow properties of the grout at the batch plant and also at the point of delivery.

Mix LP#8-16 is recommended for inclusion in the procurement specification for furnishing and delivering tank closure grout for Tanks 18-F and 19-F. The mix design is provided in Table 5-1.

Table 5-1. Tanks 18 and 19-F Bulk Fill Material Recommendation.

Mix Number	Cement Type I/II	Slag Grade 100	Fly Ash Class F	Type G Shrinkage Compensating Component	Sand Quartz	Gravel No. 8 3/8 in.	Water	HRWR SIKA Visco Crete 2100	VMA Diutan Gum Kelco-Crete DG
	Lbs/cyd						Gal / cyd	Fl oz / cyd	g / cyd
LP#8-16	125	210	363	0	1790	800	48.5	41	200

Based on small scale laboratory flow test results and knowledge of flow of this type of grout in the recent SRS reactor facility In-Situ Decommissioning Projects, the recommended grout is expected to flow at least 45 feet. A single point of discharge should be sufficient for unrestricted flow conditions. However, additional entry points should be identified as back up in case restrictions in the tank impede flow.

The Procurement Specification for the tank fill grout allows the Subcontract Technical Representative (STR) to use discretion with respect to accepting mixes that exceed the delivery temperature limit of 90°F. Since the tank curing conditions are semi adiabatic (lower than adiabatic), Material acceptance should be based on the delivery temperature.

The final recommendation is to complete the FY11 scope as outlined in Section 6.0.

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[6] A shrinkage compensating variation of this mix was being evaluated but further development and testing was postponed at the direction of SRR. The shrinkage compensating ingredient in the CompCon® component is CaO which hydrates to $Ca(OH)_2$ and has an added benefit of providing additional buffering capacity at a pH of 12.4.

6.0 FUTURE WORK

1. Complete hydraulic property testing for the recommended non shrinkage compensating mixes is recommended. This scope includes:
    - Complete characterization of moisture retention for Mixes LP#8-016 and Mixes LP#8-020 in the range of 15 to 45 bars and merge the 0 to 15 and 15 to 45 bar data to generate van Genuchten parameters and relative hydraulic conductivities for input to the PORFLOW code used in the FTF PA.
        - Samples were prepared, cured, and turned over to K. Dixon, SRNL for testing which is tentatively scheduled to begin in FY12.

2. Initiate SIMCO Moisture Test and Drying Test to obtain material specific effective diffusivities, tortuosities and saturated and unsaturated hydraulic conductivities using methods with lower detection limits than those used to obtain data presented in this report. Refer to the tank fill requirements document for details [Stefanko and Langton, 2011].
    - Prepare SOW and award contract to SIMCO Technologies to characterize Mixes LP#8- 016 and Mixes LP#8-020 samples using the SIMCO Moisture Test and Drying Test. (SRNL)
    - Analyze and report results. (SRNL)

3. Complete FY11 Scope. During August, 2011, a portion of the scope identified in HLE-TTR-2011-008 was postponed until FY12. This scope should be completed to address mitigation of the inherent potential for fast pathways and includes:
    - Final development and testing of shrinkage compensating tank fill all-in-one mix design.
        - Fresh property testing
        - Cured property testing
            - Saturated and unsaturated hydraulic properties (MACTEC/amec and SIMCO)
            - Adiabatic temperature rise (SRNL)
            - Shrinkage as a function of time, temperature, and humidity (drying) (SRNL)

4. Summarize results of the tank fill scale-up test.
    - Compile compressive strength results for samples cured for up to 90 days.
    - Summarize semi adiabatic temperature rise results from the one cubic foot form poured in F-Area and compare results to adiabatic temperature rise data.
    - Prepare report on the tank fill scale-up test.

5. Support procurement of the tank fill grout and bidder evaluation and mix qualification.

6. Provide support to Closure Project Engineering and Operations as requested to close Tanks 18-F and 19-F.

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Attachment 1. MACTEC TEST REPORT

MACTEC

engineering and constructing a better tomorrow

October 20, 2011

Savannah River Nuclear Solutions
Bldg. 730-4B Room 3016
Aiken, SC 29808

Attention: Mr. Bill Joyce, STR

Subject: **Revised Test Report – F-Area Tank Farm Grout Samples**
Subcontract No. AC54317N, Delivery Order No. 25
Specification K-SPC-G-00013, Rev. 12
MACTEC Project No. 6155-08-0031

Dear Mr. Joyce:

MACTEC Engineering & Consulting, Inc. (MACTEC) has completed the assigned testing services for Delivery Order No. 25, Subcontract No. AC54317N. The test results are included in Attachment 1. An equipment list used in this Delivery Order is included in Attachment 2. The tests performed in this Delivery Order are listed below along with applicable ASTM or other procedures:

Capillary/Moisture Relationship	ASTM D3152
Unit Weight and Moisture Content	TP-4
Permeability	ASTM D5084

These tests were performed in accordance with the above referenced contract order and MACTEC's Quality Assurance Manual (QAM) Revision 1.

A report dated October 4, 2011 was previously issued. An error was later discovered. This report supersedes the previous one dated October 4, 2011.

We appreciate the opportunity of serving your geotechnical laboratory testing needs. If you have questions, please contact us.

Sincerely,

MACTEC Engineering and Consulting, Inc.

Jianren Wang
Principal

John Lynch
Principal

Cc: SRNS
Vendor Documents
Building 704-IN/Room 137
Aiken, SC 29808

MACTEC Engineering and Consulting, Inc.
396 Plasters Avenue, NE • Atlanta, GA 30324 • Phone: 404-873-4761 • Fax: 404-817-0221

www.mactec.com

ATTACHMENT 1

MACTEC

HYDRAULIC CONDUCTIVITY

Project No.	*6155-08-0031.25*	Tested By	*JW*
Project Name	*F-Area Tank Farm Grout Sampl*	Test Date	*9/2/2011*
Boring No.	*LP#8-016A*	Reviewed By	JEJ
Sample No.	*LP#8-016A*	Review Date	10/4/11
Sample Depth	*N/A*	Lab No.	*11003*
Sample Description	*Grout*		

ASTM D5084 - Method F (CVFH)

Sample Type:	*Core*
Sample Orientation:	*Vertical*
Initial Water Content, %:	*11.3*
Wet Unit Weight, pcf:	*136.5*
Dry Unit Weight, pcf:	*122.6*
Compaction, %:	*N/A*
Hydraulic Conductivity, cm/sec. @20 °C	***3.1E-10***

Remarks:

PERMEABILITY TEST
(ASTM D5084 - 03) (Method F, Constant Volume Falling Head)

MACTEC

Project Number	6155-08-0031.25	Tested By	JW
Project Name	F-Area Tank Farm Grout Sample	Test Date	09/02/11
Boring No.	LP#8-016A	Reviewed By	JCF
Sample No.	LP#8-016A	Review Date	10/4/11
Sample Depth	N/A	Lab No.	11003
Sample Description	Grout		

Initial Sample Data				Final Sample Data	
Length, in		Diameter, in		Pan No.	N/A
Location 1	4.022	Location 1	3.014	Wet Soil+Pan, grams	1039.79
Location 2	4.043	Location 2	3.019	Dry Soil + Pan, grams	933.42
Location3	4.108	Location 3	3.016	Pan Weight, grams	0
Average	4.058	Average	3.016	Moisture Content, %	11.4
Volume, in^3	29.00	Wet Soil + Tare, grams	1039.25	Dry Unit Weight, pcf	122.6
SG Assumed	2.50	Tare Weight, grams	0.00	Saturation, %	104.7
Soil Sample Wt., g	1039.25	Dry Soil +Tare, grams	933.42	Diameter, in.	N/A
Dry UW, pcf	122.6	Moisture Content, %	11.3	Length, in.	N/A
Saturation, %	104.2			Volume, in^3	N/A

Consolidation

Chamber Pressure, psi	60
Back Pressure, psi	50
Confining Pressure, psi	10
Initial Burett Reading	0
Final Burett Reading	0
Volume Change, cc	0

Permeant used water

Elapsed Time (sec)	z_o (cm)	za (cm)	zb (cm)	Δz_p (cm)	Temp (°C)	Intial Hydraulic Gradient	Final Hydraulic Gradient	k cm/sec	k cm/sec at 20 °C
13080	1.70	28.20	27.80	0.40	23.3	32.3	31.8	6.50E-10	6.01E-10
19380	1.70	28.20	27.70	0.50	23.3	32.3	31.7	5.49E-10	5.08E-10
82620	1.70	28.20	27.20	1.00	23.2	32.3	31.1	2.60E-10	2.41E-10
104280	1.70	28.20	27.00	1.20	23.5	32.3	30.8	2.49E-10	2.29E-10
166320	1.70	28.20	26.60	1.60	23.1	32.3	30.3	2.09E-10	1.95E-10
188400	1.70	28.20	26.40	1.80	23.3	32.3	30.0	2.09E-10	1.93E-10
251520	1.70	28.20	26.00	2.20	23.2	32.3	29.5	1.93E-10	1.79E-10

No. of Trials	Sample Type	Max. Density (pcf)	Compaction %	Sample Orientation
7	Core	N/A	N/A	Vertical

Avg. k at 20 °C 3.1E-10 cm/sec

a_a = 0.76712 cm^2
A = 46.10 cm^2
L = 10.31 cm
S=L/A= 0.22356 1/cm

a_p= 0.031416 cm^2
M_1= 0.03018
M_2= 1.04095
$C = M_1S/(G_{Hg}-1)$= 0.0005368 for 15° to 25°

Remarks:

MACTEC

HYDRAULIC CONDUCTIVITY

Project No.	*6155-08-0031.25*	Tested By	*JW*
Project Name	*F-Area Tank Farm Grout Sampl*	Test Date	*9/2/2011*
Boring No.	*LP#8-020A*	Reviewed By	JCJ
Sample No.	*LP#8-020A*	Review Date	10/4/11
Sample Depth	*N/A*	Lab No.	*11004*
Sample Description	*Grout*		

ASTM D5084 - Method F (CVFH)

Sample Type:	*Core*
Sample Orientation:	*Vertical*
Initial Water Content, %:	*11.1*
Wet Unit Weight, pcf:	*136.9*
Dry Unit Weight, pcf:	*123.2*
Compaction, %:	*N/A*
Hydraulic Conductivity, cm/sec. @20 °C	***3.5E-10***

Remarks:

Revision 1

PERMEABILITY TEST
(ASTM D5084 - 03) (Method F, Constant Volume Falling Head)

MACTEC

Project Number	6155-08-0031.25	Tested By	JW
Project Name	F-Area Tank Farm Grout Sample	Test Date	09/02/11
Boring No.	LP#8-020A	Reviewed By	JEJ
Sample No.	LP#8-020A	Review Date	10/4/11
Sample Depth	N/A	Lab No.	11004
Sample Description	Grout		

Initial Sample Data				Final Sample Data	
Length, in		Diameter, in		Pan No.	N/A
Location 1	3.036	Location 1	3.013	Wet Soil+Pan, grams	773.12
Location 2	3.022	Location 2	3.011	Dry Soil + Pan, grams	695.29
Location3	2.986	Location 3	3.017	Pan Weight, grams	0
Average	3.015	Average	3.014	Moisture Content, %	11.2
Volume, in^3	21.50	Wet Soil + Tare, grams	772.53	Dry Unit Weight, pcf	123.2
SG Assumed	2.50	Tare Weight, grams	0.00	Saturation, %	105.0
Soil Sample Wt., g	772.53	Dry Soil +Tare, grams	695.29	Diameter, in.	N/A
Dry UW, pcf	123.2	Moisture Content, %	11.1	Length, in.	N/A
Saturation, %	104.2			Volume, in^3	N/A

Consolidation

Chamber Pressure, psi	60
Back Pressure, psi	50
Confining Pressure, psi	10
Initial Burett Reading	0
Final Burett Reading	0
Volume Change, cc	0

Permeant used water

Elapsed Time (sec)	z_o (cm)	za (cm)	zb (cm)	Δz_p (cm)	Temp (°C)	Intial Hydraulic Gradient	Final Hydraulic Gradient	k cm/sec	k cm/sec at 20 °C
83580	1.70	27.10	25.20	1.90	23.4	41.7	38.4	3.87E-10	3.57E-10
98700	1.70	27.10	24.90	2.20	23.7	41.7	37.9	3.82E-10	3.50E-10
110340	1.70	27.10	24.80	2.30	23.4	41.7	37.8	3.58E-10	3.31E-10
344160	1.70	27.10	20.80	6.30	22.8	41.7	30.9	3.47E-10	3.24E-10
8100	1.70	26.90	26.70	0.20	23.3	41.4	41.0	4.09E-10	3.78E-10
17200	1.70	26.90	26.50	0.40	23.3	41.4	40.7	3.87E-10	3.58E-10
43170	1.70	26.90	25.90	1.00	23.1	41.4	39.7	3.90E-10	3.63E-10

No. of Trials	Sample Type	Max. Density (pcf)	Compaction %	Sample Orientation
7	Core	N/A	N/A	Vertical

Avg. k at 20 °C 3.5E-10 cm/sec

a_a = 0.76712 cm²

A = 46.02 cm²

L = 7.66 cm

S=L/A= 0.16639 1/cm

a_p= 0.031416 cm²

M_1= 0.03018

M_2= 1.04095

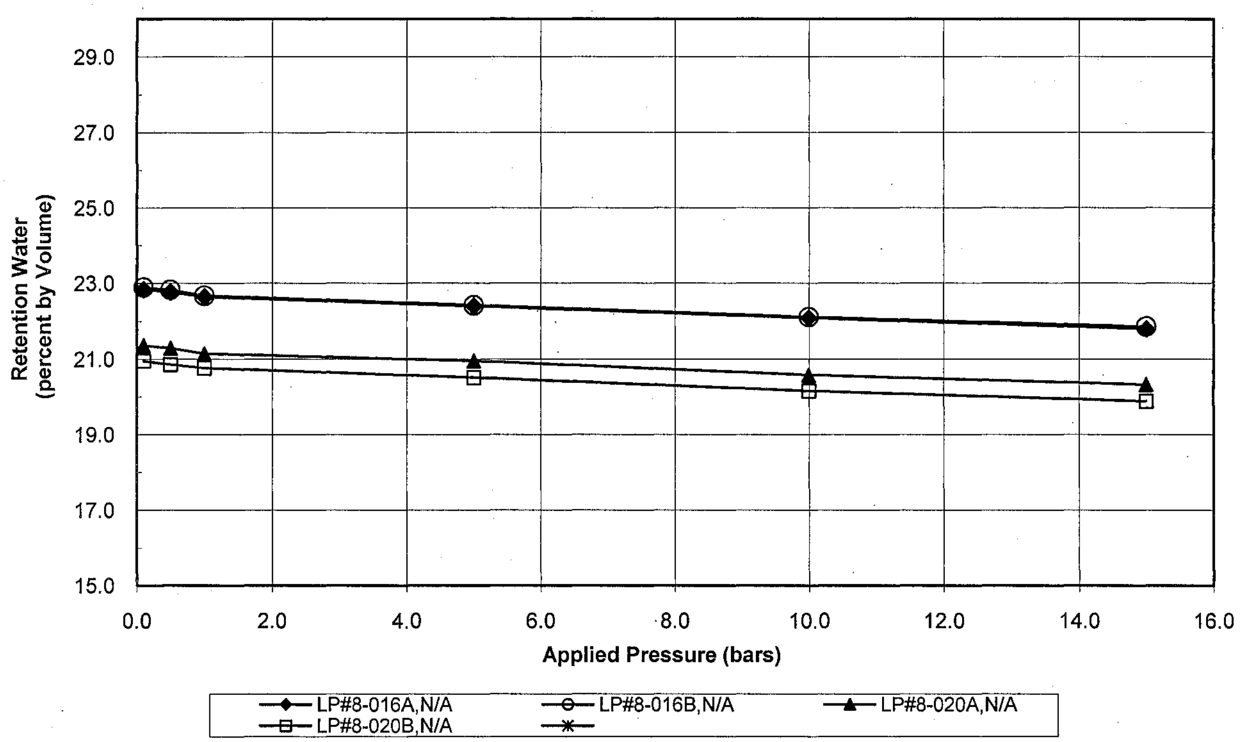
$C = M_1S/(G_{Hg}-1)$= 0.0003995 for 15° to 25°

Remarks:

MACTEC

Water Retention Test
(ASTM D3152-72 (1994))

Project No	6155-08-0031.25	Project Name	F-area Tank Farm Grout Samples
Tested By	JW	Test Date	9/9/11-10/4/11
Reviewed By	JEJ	Review Date	10/20/11



Sample No. & Depth (ft)	Initial Moisture % by Vol.	Dry Unit Weight (pcf)	Applied Pressure (bars) 0.10	0.50	1.0	5.0	10.0	15.0				
			Retained Water (percent by volume)									
LP#8-016A,N/A	23.1	122.2	22.8	22.8	22.6	22.4	22.1	21.8				
LP#8-016B,N/A	23.1	119.4	22.9	22.8	22.7	22.4	22.1	21.9				
LP#8-020A,N/A	21.8	122.2	21.4	21.3	21.1	20.9	20.6	20.3				
LP#8-020B,N/A	21.5	120.8	21.0	20.9	20.8	20.5	20.2	19.9				

Remarks: The effective porosity (effective drainage porosity as defined by ASTM D653, as a percent, is found for an applied pressure by subtracting the retained percent water (by volume) from the saturation percent water.
When testing at pressures higher than one bar, ASTM D2325 using similar equipment designed for the required capacity.

Revised Report

MACTEC

Revision 1

Water Retention Test
(ASTM D3152-72 (1994))

Project No	6155-08-0031.25	Project Name	F-area Tank Farm Grout Samples
Tested By	JW	Test Date	9/9/11-10/4/11
Reviewed By	JEF	Review Date	10/20/11

Remarks: Revised Report

Boring No.	LP#8-016A	LP#8-016B	LP#8-020A	LP#8-020B	
Sample No.	LP#8-016A	LP#8-016B	LP#8-020A	LP#8-020B	
Depth (ft)	N/A	N/A	N/A	N/A	
Lab No.	11003A	11003B	11004A	11004B	
Ring No.	N/A	N/A	N/A	N/A	
Container Weight. (g)	0.00	0.00	0.00	0.00	
Container Diameter (cm)	7.63	7.66	7.65	7.66	
Container Height, (cm)	2.66	2.75	2.19	2.32	
Container Volume (cm^3)	121.57	126.51	100.53	106.73	
Wt. of Wet Soil + Container (g)	266.11	271.39	218.75	229.47	
Wt. of Dry Soil + Container (g)	238.02	242.13	196.81	206.54	
Moisture Content (%)	11.8	12.1	11.1	11.1	
Dry Unit Weight (pcf)	122.17	119.43	122.16	120.75	
Initial Wt.Wet Soil + Container (g)	266.11	271.39	218.75	229.47	
Initial Wt. Container (g)	0.00	0.00	0.00	0.00	
Initial Moisture, % by Volume	23.1	23.1	21.8	21.5	

Lab No.	Pressure										
	psi	1.45	7.26	14.51	72.55	145.1	217.65				
	bars	0.1	0.50	1.0	5.0	10.0	15.0				
	Date / Read By	9/14/2011	9/16/2011	9/22/2011	9/26/2011	9/27/2011	9/29/2011				
11003A	Weight of Soil + Ring	265.78	265.7	265.54	265.25	264.87	264.52				
LP#8-016A	Weight of Ring	0	0	0	0	0	0				
N/A	Retained Water (%)	22.8	22.8	22.6	22.4	22.1	21.8				
11003B	Weight of Soil + Ring	271.09	271.01	270.81	270.49	270.1	269.78				
LP#8-016B	Weight of Ring	0	0	0	0	0	0				
N/A	Retained Water (%)	22.9	22.8	22.7	22.4	22.1	21.9				
11004A	Weight of Soil + Ring	218.28	218.21	218.06	217.87	217.49	217.24				
LP#8-020A	Weight of Ring	0	0	0	0	0	0				
N/A	Retained Water (%)	21.4	21.3	21.1	20.9	20.6	20.3				
11004B	Weight of Soil + Ring	228.9	228.8	228.7	228.43	228.05	227.76				
LP#8-020B	Weight of Ring	0	0	0	0	0	0				
N/A	Retained Water (%)	21.0	20.9	20.8	20.5	20.2	19.9				

No. of Samples 4

No. of Tests per Sample 6

MACTEC

TP-4 UNIT WEIGHT OF SAMPLE

Project No.:	6155-08-0031.25	Boring No.:	LP#8-016A
Project Name:	F-Area Tank Farm Grout Samples	Sample No.:	LP#8-016A
Lab No.	11003	Depth:	N/A
Tested By:	EH	Reviewed By:	JW
Date:	09/02/11	Date:	09/26/11

Total Sample Height, *inches*		**Inside Diameter of Cut Tube, *inches***		**Moisture Content**		
1	4.022			Tare No.	N/A	
2	4.043	Top	3.016	Tare Weight	0.00	*grams*
3	4.108	Bottom	3.016	Wet Weight + Tare	1039.25	*grams*
Average	4.058	Average	3.016	Dry Weight + Tare	933.42	*grams*
				Moisture Content	11.3	%

Total Weight of Soil + Tube Section	1039.25	*grams*
Weight of Clean, Dry Tube Section	0.00	*grams*
Wet Weight of Soil	2.29	*lbs*
Volume of Sample	0.017	ft^3

RESULT SUMMARY

Moisture Content	**11.3**	%
Wet Density	**136.6**	*pcf*
Dry Density	**122.7**	*pcf*
Specific Gravity	**2.5**	
Porosity	**0.21**	

Remarks:

MACTEC

TP-4 UNIT WEIGHT OF SAMPLE

Project No.:	6155-08-0031.25	Boring No.:	LP#8-020A
Project Name:	F-Area Tank Farm Grout Samples	Sample No.:	LP#8-020A
Lab No.	11004	Depth:	N/A
Tested By:	EH	Reviewed By:	JW
Date:	09/02/11	Date:	09/26/11

Total Sample Height, *inches*		**Inside Diameter of Cut Tube, *inches***		**Moisture Content**		
1	3.026			Tare No.	N/A	
2	3.022	Top	3.014	Tare Weight	0.00	*grams*
3	2.986	Bottom	3.014	Wet Weight + Tare	773.12	*grams*
Average	3.011	Average	3.014	Dry Weight + Tare	695.29	*grams*
				Moisture Content	11.2	%

Total Weight of Soil + Tube Section	773.12	*grams*
Weight of Clean, Dry Tube Section	0.00	*grams*
Wet Weight of Soil	1.70	*lbs*
Volume of Sample	0.012	ft^3

RESULT SUMMARY

Moisture Content	**11.2**	%
Wet Density	**137.1**	*pcf*
Dry Density	**123.3**	*pcf*
Specific Gravity	**2.5**	
Porosity	**0.21**	

Remarks:

ATTACHMENT 2

Equipment List
SRNS Delivery Order No. 25
Subcontract No. AC54317N

Equipment Name	Laboratory ID
Oven	109
Balance	416
Thermometer	2866
Caliper	2424
Pressure Transducer	1872/2908

Distribution:

A. B. Barnes, 999-W
H. H. Burns, 773-43A - Rm.227
D. A. Crowley, 773-43A
W. C. Elkins, 717-11F
S. D. Fink, 773-A
R. W. Forty, 742-5G
B. J. Giddings, 786-5A
J. E. Herbert, 241-108F
C. C. Herman, 999-W
J. P. Hyche, 704-70F
R. C. Jolly, Jr.,
W. L. Isom Jr., 704-26F
S. L. Marra, 773-A
B. A. Martin, 705-1C
W. L. Mhyre, 717-5N
A. M. Murray, 773-A
M. E. Pallon, 717-11F
F. M. Pennebaker, 773-42A
W. Pope, Jr., 717-5N
J. L. Steimke, 786-5A
K. H. Rosenberger, 705-1C
J. W. Rush, 241-108F
J. H. Scogin, 773-A
M. G. Serrato, 773-42A
A. J. Tisler, 704-26F
J. T. Waymer, 717-5N
W. R. Wilmarth, 773-A
D. C. Wood, 704-26F
STI
File