Use of Cementitious Materials for SRS Reactor Facility In-Situ Decommissioning – 11620

C. A. Langton[1], D. B. Stefanko[1], M. G. Serrato[1], J. K. Blankenship[2] and W. B. Griffin[2]
J. T. Waymer[3] D. Matheny [4], and D. Singh[5]

[1]Savannah River National Laboratory, Savannah River Nuclear Solutions
Savannah River Site, Aiken SC 29808

[2]Savannah River Nuclear Solutions, Savannah River Site, Aiken SC 29808

[3]URS Washington Group, Quality and Testing Division, Savannah River Site, Aiken SC 29808

[4]Clemson University, Clemson, SC 29634

[5]Argonne National Laboratory, Argonne, IL 60439

ABSTRACT

The United States Department of Energy (US DOE) concept for facility in-situ decommissioning (ISD) is to physically stabilize and isolate in tact, structurally sound facilities that are no longer needed for their original purpose of, i.e., producing (reactor facilities), processing (isotope separation facilities) or storing radioactive materials. The Savannah River Site 105-P and 105-R Reactor Facility ISD requires about 250,000 cubic yards of grout to fill the below grade structure. The fills are designed to prevent subsidence, reduce water infiltration, and isolate contaminated materials. This work is being performed as a Comprehensive Environmental Response, Compensations and Liability Act (CERCLA) action and is part of the overall soil and groundwater completion projects for P- and R-Areas.

Cementitious materials were designed for the following applications:

- Below grade massive voids / rooms: Portland cement-based structural flowable fills for:
  - Bulk filling
  - Restricted placement and
  - Underwater placement.
- Special below grade applications for reduced load bearing capacity needs:
  - Cellular portland cement lightweight fill
- Reactor vessel fills that are compatible with reactive metal (aluminum metal) components in the reactor vessels
  - Calcium sulfoaluminate flowable fill
  - Magnesium potassium phosphate flowable fill.
- Caps to prevent water infiltration and intrusion into areas with the highest levels of radionuclides
  - Portland cement based shrinkage compensating concrete

A system engineering approach was used to identify functions and requirements of the fill and capping materials. Laboratory testing was performed to identify candidate formulations and develop final design mixes. Scale-up testing was performed to verify material production and placement as well as fresh and cured properties. The 105-P and 105-R ISD projects are currently in progress and are expected to be complete in 2012.

The focus of this paper is to describe the 1) grout mixes for filling the reactor vessels, and 2) a specialty grout mix to fill a selected portion of the P-Reactor Disassembly Basin. (Details of the grout mixes designed for ISD of he SRS Reactor Disassembly Basins and below grade portions of the 105-Buildings was described elsewhere [1]. Material property test results, placement strategies, full-scale production and delivery systems will also be described.

INTRODUCTION

The Savannah River Site (SRS) was built in the early 1950's with the mission of producing special nuclear materials in a safe, efficient, and environmentally acceptable manner. The special nuclear materials were produced in five production reactors primarily for national defense. R-Reactor was initially brought critical on December 28, 1953 and operated intermittently until it was shutdown on June 15, 1964 due to reduced requirements for defense-related products. Following shutdown, the R Reactor was de-fueled (all fissile materials were removed), and placed in cold shutdown with no capability of restart. P-Reactor initially went critical in February 20, 1954 and was placed in an extended outage in 1988 to undergo safety upgrades. It was never restarted. Defueling began in 1991 and the facility was placed in cold shut down after de-fueling was completed.

The P- and R-Reactor Complexes were designated to be decommissioned as part of CERCLA remedial actions with an assumed end state of "in situ decommissioning". The facilities are the first SRS facilities to undergo the In-Situ Decommissioning (ISD) process. This process consists of:

- Dewatering the disassembly basin,
- Filling the below grade structure and reactor vessel with flowable cementitious grout,
- Sealing the building openings with reinforced concrete,
- Installing sloped reinforced shrinkage compensating concrete slabs on the existing flat roof surfaces to prevent water ponding,
- Removing the gantry crane,
- Demolishing the stack,
- Demolishing the Disassembly Basin above ground structures,
- Installing shrinkage compensating concrete caps over the Disassembly Basin and Reactor Vessel.

The SRS reactor facilities are structurally robust and complete demolition was determined to be unnecessary. The ISD process complies with the105-R and 105-P Reactor Project Strategy as outlined in the Engineering Evaluation/Cost Analysis for the Grouting of the R-Reactor Disassembly Basin [2] and the Removal Site Evaluation Report/Engineering Evaluation/Cost Analysis (RSER/EE/CA) for the 105-R Reactor Building Complex [3].

The ISD objectives for these facilities include [3]:

- Prevent industrial worker exposure to radioactive or hazardous contamination exceeding Principal Threat Source Material levels.
- Prevent industrial worker exposure to radioactive or hazardous contamination.
- Prevent to the extent practicable the migration of radioactive or hazardous contaminants from the closed facility to the groundwater so that concentrations in the ground water do not exceed regulatory standards.
- Prevent animal intruder exposure to radioactive or hazardous contamination.

The SRS 105-P reactor facility is shown in Figure 1 and is very similar to 105-R reactor building. The ISD concept for both 105-P and 105-R are illustrated in schematic cross sections in Figures 2 and 3. (The cross sections correspond to the red line on Figure 1.)

BELOW GRADE FACILITY IN-SITU DECOMMISSIONING

Material requirements, pertinent test data and information related to the grout formulations used in the majority of the below grade facilities are provided elsewhere [Langton, et al., 2010]. Three grout mixes were developed for filling the massive voids / rooms below grade. These grouts utilize zero bleed, flowable structural fill technology developed at the Savannah River National Laboratory. These grouts are based on a portland cement – Class F fly ash binder and were specified for the following applications:

- Below grade massive voids / rooms: Portland cement-based structural flowable fills for:
  - Bulk filling
  - Restricted placement and
  - Underwater placement.

A cellular (light weight) grout was also specified for filling a portion of the P-Reactor Disassembly Basin. This grout was produced at the job site by mixing preformed foam into a portland cement slurry batched at an off-site ready-mix plant. A loading limit for the basin floor was the driver for specifying a cellular grout. The density of the cellular grout was about 480 to 560 kg/m^3 (30 to 35 lbs/ft^3). Surfactant was used to generate the foam.

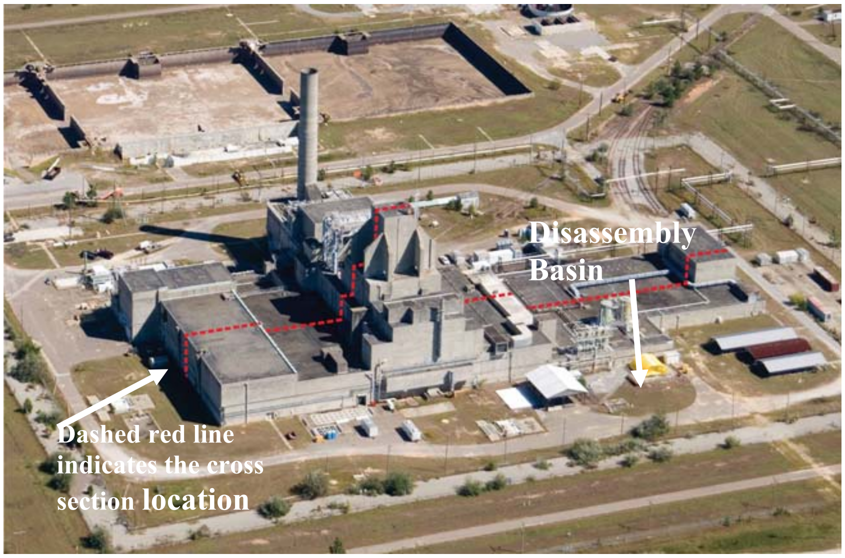


Figure 1. Photo of the 105-P reactor building (similar to the 105-R building). Dashed red line indicates the cross sections in Figures 2 and 3.

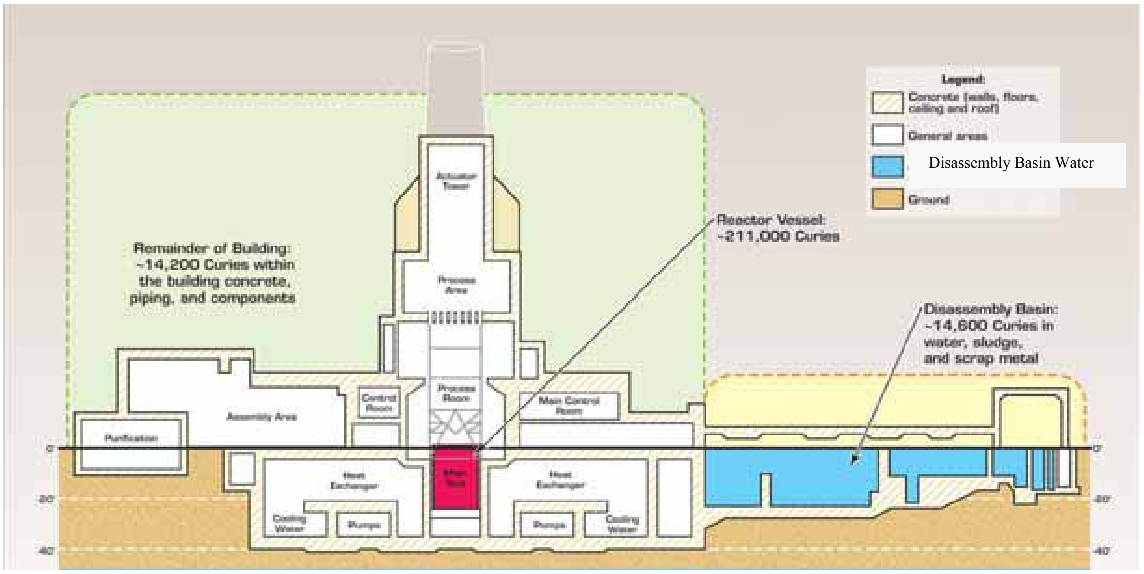


Figure 2. Cross-section through 105-P (105-R) reactor building before ISD.

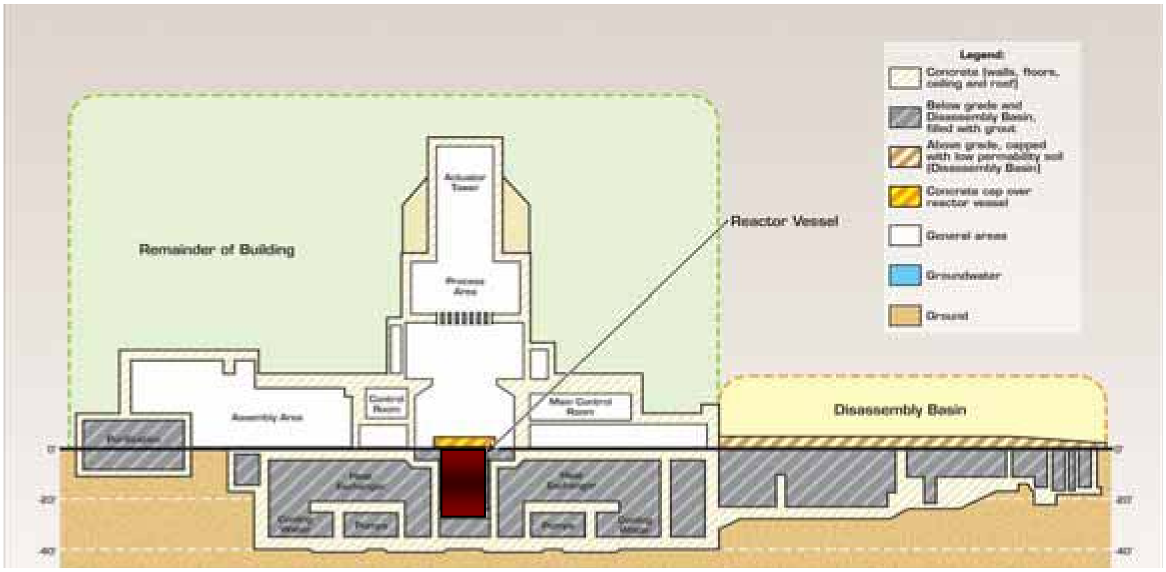


Figure 3. Cross-section through 105-P (105-R) reactor building after ISD.

Gray hatched regions indicate areas to be filled with zero bleed flowable structural fills. The dark red area indicates the grouted reactor ISD grout. A non corrosive low-pH grout was designed for P-Area. Yellow and orange hatched areas indicate a 3000 psi shrinkage compensating capping concrete containing an integral waterproofing admixture.

Ingredients in these flowable structural fills are presented in Table 1. Selected properties of these grouts are presented in Table 2.

Table 1. SRS Reactor Facility ISD Structural Fill Grout Mix Designs.

Material	**Conjested Dry Area Placements**	**Unconjested Dry Area Placements**		**Underwater Placements**
(kg / m^3) (lbs / yd^3)	**PF-ZB-FF**	**PF-ZB-FF-8**	**PF-ZB-FF-8-D**	**PR-UZB-FF-8**
Portland Cement Type I/II	89 *(150)*	89 *(150)*	89 *(150)*	89 *(150)*
Fly Ash Class F (ASTM C 618)	297 *(500)*	297 *(500)*	297 *(500)*	297 *(500)*
Sand (quartz) (ASTM C-33)	1375 *(2318)*	1008 *(1700)*	1850 *(1097)*	1086 *(1832)*
Gravel (granite) No. 8	0	475 *(800)*	475 *(800)*	475 *(800)*
Water (kg / m^3) *(lb / cu yd)*	525 *(311)*	441 *(262)*	416 *(247)*	344
(gal / cu yd)	*(63)*	*(53)*	*(50)*	*(41.5)*
Polycarboxylate polymer HRWR max. (L / m^3) *(fl. oz / cu yd)*	0.46* *(120)**	0.30* *(79)**	0.30* *(79)**	0.26** *(68)***
VMA (g / m^3) *(g / cu yd)*	360W *(275)*W	360W *(275)*W	262D *(200)*D	0

* SIKA Inc. Viscocrete 2100 and 6100 and W. R. Grace Inc. Advacast 575 were tested and found to be compatible with the gum VMA. Compatibility was defined as being capable of forming a fluid slurry when premixed with the gum VMAs.

* * W.R. Grace Adva 405 was tested.

W = Welan Gum

D = Diutan Gum

A calcium nitrite based set accelerator can be added if necessary. No instance was encountered where set acceleration was necessary.

Table 2. SRS Reactor Facility ISD Structural Fill Grout Properties.

Properties	**Conjested Dry Area Placements**	**Unconjested Dry Area Placements (Bulk Fill)**		**Underwater Placements**
	PF-ZB-FF	**PF-ZB-FF-8**	**PF-ZB-FF-8-D**	**PR-UZB-FF-8**
Flow (cm) *(inches)* ASTM D-6103	29 *(11.5)*	29 *(11.5)*	33 *(13)*	24 *(9.5)*
Flow (cm) *(inches)* ASTM C-1611	Not measured	63 *(25)*	66 *(26)*	48 *(19)*
Set Time* (hr) modified ASTM C-403 and SRNL ultra sonic pulse velocity	< 18	< 16	< 16	< 10
Bleed Water (hr) modified ASTM C-232	0	0	0	0
Unit Weight (g/cc) (lb/cu ft) ASTM C-138	2.0 *(127.5)*	2.15 *(134.5)*	2.20 *(137.5)*	2.18 *(135.8)*
Compressive Strength (ave. of 2) ASTM C-39, D-4832 for field sampling				
7 days (MPa) *(psi)*	1.1 *(160)*	1.4 *(200)*	Not measured	2.6 *(380 @ 14d)*
28 days (MPa) *(psi)*	2.7 *(390)*	3.7 *(540)*	5.4 *(780)*	5.6 *(820)*
90 days (MPa) *(psi)*	TBD	TBD	TBD	TBD
180 days (MPa) *(psi)*	TBD	TBD	TBD	TBD
Permeability (cm/s) ASTM D-5084	1E-07	Not measured	1.3E-08	1.3E-08
Temperature Rise (calculated semi-adiabatic)	< 25°C	< 25°C	< 25°C	< 25°C

* Values without set accelerator.

Two concrete ready mix plants were set up in P-Area to support P-and R-Reactor Facilities ISD. Additional material was supplied by LaFarge Ready Mix, Jackson, SC and Webb Concrete, Barnwell, SC. See Figure 4a. Portable concrete pumps and pump trucks were used to convey the grout into the P- and R- Reactor Disassembly Basins and the below grade portions of the 105-Buildings. See Figure 4b. Examples of the types of large voids filled with PR-ZB-FF-8-D are illustrated in Figure 5. Examples of these rooms and basins filled or being filled with grout are shown in Figure 6. Cellular grout production and conveyance for the P-Reactor Disassembly Basin is illustrated in Figure 7.

Figure 4. Two On-site concrete batch plants located in P-Area used to produce ISD fill (left) and delivery and pumping of ISD grout in the R-Reactor Disassembly Basin (right).

Figure 5. Examples of rooms at the -20 and -40 levels before ISD.
Fan room at -40 level (left) and Heat Exchanger Pit at -20 level (right).

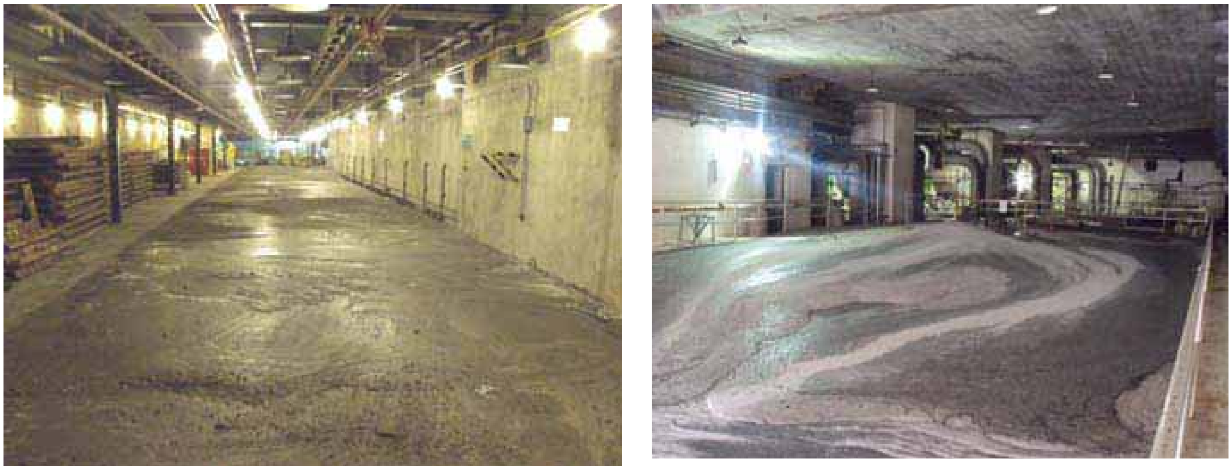


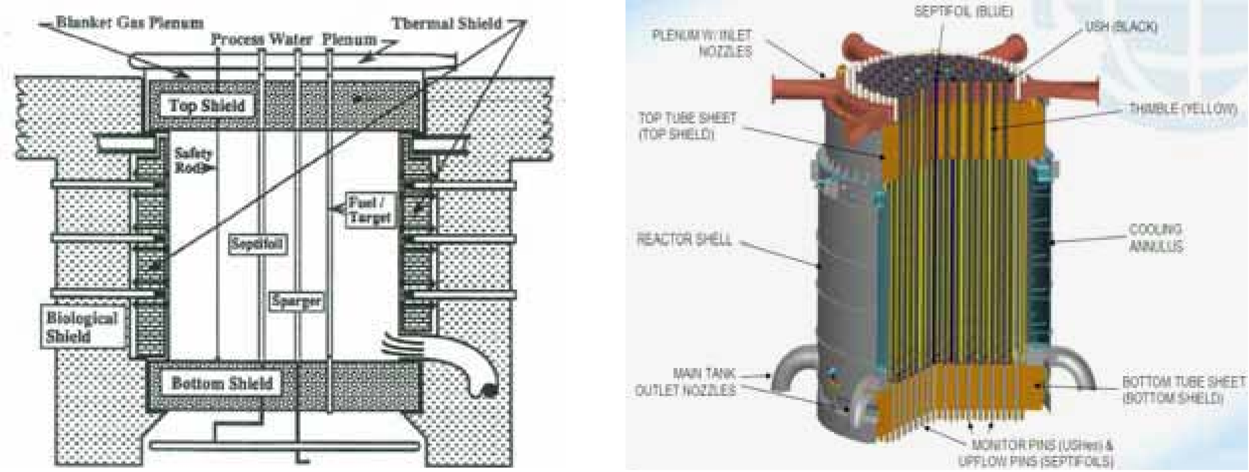
Figure 6. R-Reactor D&E Canal after ISD (left). P-Reactor Heat Exchanger Pit after ISD (right).

Figure 7. Cellular grout production for P-Area Disassembly Basin. Pre-formed foam added to neat cement slurry (left) and cellular grout being discharged to pump (right).

REACTOR VESSEL IN-SITU DECOMMISSIONING

SRNS committed to the Department of Energy (DOE) that it would fill the reactor vessels in 105-P and 105-R buildings with grout to the extent practicable as part of the SRS reactor Facilities ISD Projects. The main tank (referred to as the reactor vessel) in each reactor was constructed of 304 stainless steel and is 4.9 m (16 ft.) in diameter and 4.9 m (16 ft.) high. The bottom and top of each tank are capped with Tube Sheets approximately 1.2 m (4 ft.) and 1m (3.5 ft) in height, respectively. The top tube sheet is covered with a plenum which is approximately 0.6 m (2 ft.) high. A steel shell around each reactor vessel forms a Thermal Shield around each tank with a Cooling Annulus of about 0.5m (21 in.) wide. The steel shell is surrounded by a five foot thick Biological Shield consisting of reinforced concrete. These features are illustrated for the P-Reactor Vessel in a simplified cross section and in a 3-D schematic in Figure 8a and 8b, respectively.

A view of the top of the P-Reactor plenum is shown in Figure 9. The ISD grout fill strategy for each of the reactor vessels was to pull plugs in 3 permanent sleeve openings along the circumference of the vessel and use these positions as grout entry points into the vessel. (Two entry points on opposite sides of the tank will be used for filling the R-Reactor Vessel.)



(a) (b) (after Vrettos, 2010) [4]

Figure 8 a and b. P-Reactor cross sections.

Figure 9. Top of the P-Reactor plenum.

General requirements for the reactor vessel grout were the same as for the 105-R and 105-P Buildings except that the flow paths in the 105-P reactor vessel are especially constricted due to numerous internal components. See Table 3. In addition, the need for material compatibility between the grout and reactor materials imposed additional requirements. Both the P-and R-Reactor Vessels contain aluminum components which were left in place as part of the ISD closure. After estimating the amount of aluminum metal abandoned in each reactor, calculations were performed to estimate the potential for exceeding 60 % of the Lower flammability Limit (LFL) as the result of hydrogen generation from corrosion of the aluminum in caustic media.[1] Results indicated that the limited amount of aluminum metal in the R-Reactor did not pose an LFL issue if portland cement-based grout was used to fill the vessel [5, 6]. However, the safety factor calculated for the portland cement fill for the P-reactor vessel, which contained significantly more aluminum metal, was such that the decision was made to investigate alternative low pH grout systems. The calculations indicated that a higher safety factor could be achieved for grouts with pHs ≤ 10.5 [5].

In addition, calculations to determine the effects of radiolysis on the water and organic admixtures used as processing aids in the grouts were performed [7]. Hydrogen produced by radiolysis was determined to not impact the LFL for the reactor vessel closure configuration.

Table 3. SRS ISD Reactor Vessel Grout Fill Requirements.

Property	Requirement	Comments
Slurry Properties (Fresh Properties)		
pH of grout for the P-Reactor Vessel	≤ 10.5	Aluminum corrosion rate [Weirsma, 2010]
pH of grout for the R-Reactor Vessel	≤ 13.4	Aluminum corrosion rate [Weirsma, 2010]
Flow Cone (ASTM C-939)	< 50 s	Flowable, self leveling (desired)
Spread/Flow (ASTM C-1611)	> 24 in.	
Static Working Time (SRNL test)	> 30 min.	Grout needs to remain fluid as the velocity decreases (to zero) as a function of distance from the discharge point in the reactor vessel
Dynamic Working Time (SRNL test)	> 60 min.	Longer is better
Set Time (SRNL UPV test)	2 to 24 hr	Sufficient time to prevent settling
Density (wet unit weight) Unit Weight (lb/cu ft) ASTM C-138	> 80 lbs/ ft^3 1282 kg/m^3	Pumpable through 1-2 inch ID hose
Air Content (ASTM C-231)	< 8 vol.%	
Bleed water (modified ASTM C-232)	None	Physically stable slurry is required
Segregation (visual exam)	None	Physically stable slurry is required
Maximum particle size	3 mm maximum	< 0.5 mm may be necessary pending further understanding of reactor vessel construction
Cured Properties		
Compressive Strength ASTM C-39		
3 days	> 0.34 MPa (50 psi)	50 psi required in regulatory documentation
28 days	> 1.38 MPa (200 psi)	
Adiabatic temperature rise (SRNL method)	< 65°C	As low as possibly and still achieve compressive strength.
Maximum placement temperature	35°C	Suitable for mass pours

---

[1] Portland cement-based slurries are alkaline and typically have a pH between 12.4 and 13.2. The pore solution in cured portland cement-based grouts is also alkaline and has a pH similar to the wet slurry.

R-Reactor Vessel ISD Grout: A portland cement-based grout, MIX PR-ZB-FF-8-D, which was used for filling the majority of the void space in the P- and R-Reactor Facility, was selected as the ISD grout for the R-Reactor Vessel. Ingredients and properties of this mix are listed in Tables 1 and 2, respectively.

P-Reactor Vessel ISD Grout: Based on estimates of the amount and rate of H_2 generated as the result of corrosion of the aluminum components abandoned in place in the P-Reactor Vessel and the desire to maintain a high safety factor with respect to not exceeding 60% of the LFL, a program was initiated to develop a low pH flowable grout for P-Reactor Vessel ISD. Two alternative cement systems were investigated as potential low-pH binders for formulating a non portland cement based grout:

1) Magnesium potassium phosphate cement based on Ceramicrete® technology [8].

$$\mathbf{MgO + KH_2PO_4 + 5\ H_2O \rightarrow Struvite\ MgKPO_4{\cdot}6H_2O}$$

2) Calcium sulfo-aluminate cement.

$$\mathbf{CaAl_2O_6 + 3\ CaSO_4 + H_2O \rightarrow Ettringite\ (CaO){\cdot}3(Al_2O_3){\cdot}3(CaSO_4)\cdot 32\ H_2O + Al(OH)_3}$$

Magnesium mono-potassium phosphate grouts. A series of screening tests were conducted concurrently at SRNL and at Argonne National Laboratory (ANL). [2] The formulations tested at ANL contained MgO, mono-potassium phosphate (MKP), and Class C fly ash as functional filler. Some mixes also contained general purpose sand as an inert filler to reduce the heat generated per unit volume of material. Incorporating the Class C fly ash in these mixes enabled the use of higher doses of set retarder (boric acid) which extended the dynamic working time of the grout slurries. Flowable grouts with dynamic working times of several hours were developed at ANL [8]. These mixes were characterized by continuous slow hydration over several weeks. Although the ANL slurries had pHs of 6 to 8, the pH of water in contact with material cured in the adiabatic calorimeter had a pH of 11.2 which is higher than the 10.5 limit recommended for P-Reactor vessel grout [6]. The high pH was probably due to un-reacted calcium oxide from the fly ash and / or un-reacted magnesium oxide reagent. For this reason and because these mixes continued to react and generate heat for several weeks[3] under adiabatic conditions, this system was not selected as a reactor fill. Additional information on these formulations is provided elsewhere [8].

Testing at SRNL focused on identifying commercially available magnesium phosphate pre-blended binders and modifying them with inert fillers to achieve a zero bleed, flowable slurry and to reduce the heat generated per unit volume from the MgO and MKP reactions. Several pre-blended MgO-MKP-set retarded blends were provided by Bindan Corporation, Chicago, IL. Special graded sands, glass beads, bauxite beads, locally available ASTM C 404 masonry sand, and ASTM C-637 pre-placed aggregate sand were tested in the grout mixtures. Class F fly ash was also evaluated as an additional inert ingredient to improve flow, reduce segregation, and reduce heat. Grouts containing MgO, MKP, quartz sand, and Class F fly ash had a pH of 6 to 7 for the slurry and between 9 and 10 for water in contact with cured material (approximated pore solution). An integral water proofing admixture which was specified by SRS Reactor Engineering was also included in the SRNL mixes. Details of the test results are provided elsewhere [9].

---

[2] D. Singh, ANL, is a co-inventor of the Ceramicrete® technology which has been applied to waste forms.

[3] An aggressive project schedule called for construction of a cap over the reactor vessel within about two week of filling.

The formulation that contain inert fillers, i.e., Class F fly ash or silica flour, silica sand, etc., were preferred over formulations containing functional fillers that were somewhat reactive.[4] A bimodal distribution of inert fillers (powder and sand) was found to be beneficial in obtaining both flowable stable slurries and high inert fill loadings. An interesting observation was that a temperature of at least 65°C was necessary to form a significant amount of struvite from the starting materials used in this study. At lower temperatures, other hydrated magnesium potassium phosphate phases that were not cementitious formed. This temperature corresponds to the temperature reached for 22°C starting materials containing 15.5 weight percent Bindan SR 3.10 binder cured in the adiabatic calorimeter.

Ingredients in the magnesium potassium phosphate-based grout recommended for scale-up testing are listed in Table 4. Chilled water was recommended to reduce the initial mix temperature and extend the working time.

Table 4. Ingredients and properties of the Magnesium Potassium Phosphate Grout identified for P-Rreactor Vessel ISD scale-up testing.

Ingredient	**(Lbs/yd^3)**	**(Kg/m^3)**
Bindan SR 3.10 Binder	549.6	326.1
Class F Fly Ash	673.7	399.4
ASTM C 404 Masonry sand or ASTM C 637 Sand for grout for pre-placed aggregate	1836.8	1089.7
KIM 301 (Integral Water Proofing Admixture)	5.5	3.3
Water	478.7	284.0
Boric Acid (if needed)	Up to 2 wt.% of the binder	
Total	3544	2103
Properties		
pH of fresh slurry or P-Reactor Vessel	6 to 7	
pH of water in contact with cured grout Vessel	9 to 10	
Flow Cone	40 s (ave)	
Static Working Time	30 minutes	
Dynamic Working Time	2 hr	
Set Time	~ 4 hr (initial)	
Density (wet unit weight)	129 lbs/cubic foot 1986 kg/m3	
Bleed water	None	
Segregation	None	
Maximum particle size ASTM C 637 quartz sand	1 mm maximum	
Cured Properties		
Compressive Strength		
1 days	6.62 MPa (960 psi)	
7 day	6.8 MPa (ave)	
28 days	6.8 MPa (ave)	
Adiabatic temperature rise	41°C	

---

[4] Class F fly ash is not a pozzolan in the calcium sulfo-aluminate system.

Calcium sulfo-aluminate grout system. A calcium sulfo-aluminate cement binder was formulated from a mixture of Ciment Fondu® and Plaster of Paris (calcium hemihydrate) to produce a grout system with pHs between 9 and 10 for both the slurry and pore solution in the cured product. The proportioning of these ingredients was such that it supplied the sulfate necessary to react with the calcium aluminate cement phases to produce ettringite and aluminum hydroxide as the primary reaction products. The objective was to produce ettringite as the stable, end-state cementitious phase. This binder was mixed with Class F fly ash, ASTM -404 masonry sand or ASTM C-637, and a set retatder (boric acid).

Screening tests were performed to identify proportions and suitable set retarders. Detailed results are presented elsewhere [10]. Adiabatic calorimeter measurements indicated the temperature rise for the calcium sulfo-aluminate grouts were about 10°C less than that of the magnesium potassium phosphate grouts. Two mixes are shown in Table 5. The amount of binder in each mix is identical, but the water to binder ratio was varied.[5] Mixes were proportioned volumetrically and the sand volume was used to balance the difference in water volumes of the two mixes. Adjustments were also made in the processing admixtures. Properties for these mixes are listed in Table 6.

The calcium sulfo-aluminate mix with a water to binder ratio of 1.41 was selected for scale-up testing which was conducted at Gibson's Pressure Grouting Service, Inc., Smyrna, GA. The test consisted of mixing, pumping, and placing 6 cubic yards of material. Mixing time, flow through 400 ft. of 2 inch grout hose, recirculation time (dynamic working time) and semi adiabatic heat generation (one cubic yard instrumented block) were evaluated. A grout placement test into a ¼ scale mock-up vessel was also conducted. Grout batching and pumping equipment used in the scale-up test were smaller but the same type of equipment as that used for full scale production. See Figure 10.

Table 5. Calcium sulfo-aluminate grout mixes developed for the P-Reactor Vessel ISD.

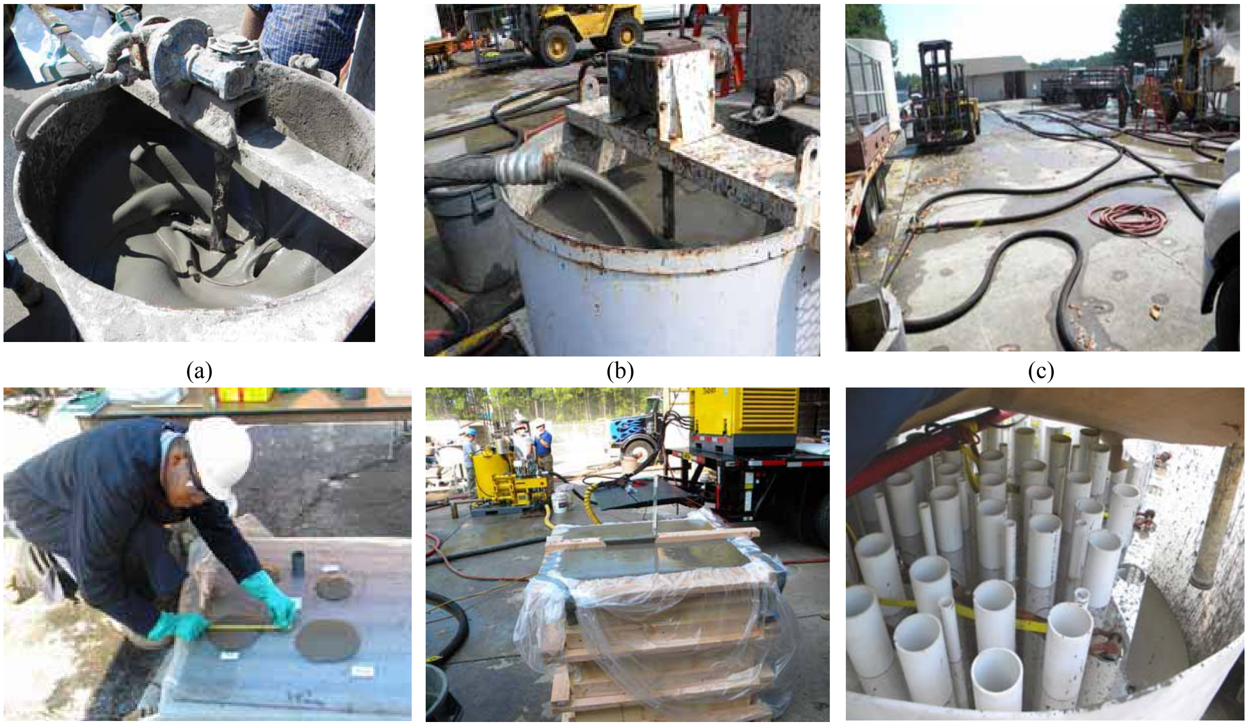
Ingredient	**Water to binder weight 1.41**		**Water to binder weight 1.24**	
	(Lbs/yd^3)	**(Kg/yd^3)**	**(Lbs/yd^3)**	**(Kg/yd^3)**
Ciment Fondu (Kerneos Aluminate Technologies)	304.3	180.5	304.3	180.5
Plaster of Paris (US Gypsum Corp.)	152.2	90.3	152.2	90.3
Class F Fly Ash (SEFA, Inc.)	514.8	305.4	514.8	305.4
ASTM C 404 Masonry sand or ASTM C 637 Sand for grout for pre-placed aggregate	1732.0	1027.6	1937	1149
Water	644.3	382.2	566.9	366.4
KIM 301 (Integral Water Proofing Admixture) (Kryton, Inc.)	4.5	2.7	4.5	2.7
SIKA (W.R. Grace, Inc.)	3.1	1.8	3.4	2.0
Diutan Gum (CP Kelco, Inc.)	0.5	0.3	0.17	0.1
Boric Acid (if needed)	3.4	2.0	3.4	2.0
Total	3359	1993	3487	2069

---

[5] The water to binder ratio for calcium sulfo-aluminate cement systems is higher than that of typical portland cement mixes.

Table 6. Properties of the calcium sulfo-aluminate grouts for P-Reactor Vessel ISD.

Property	**Water to binder weight 1.41**	**Water to binder weight 1.24**
Slurry Properties (Fresh Properties)		
pH P-Reactor Vessel	9 to 10 fresh slurry and water in contact with cured sample	9 to 10 fresh slurry and water in contact with cured sample
Flow Cone	40 s (ave)	Not measured
Static Working Time	45 min.	45 minutes
Dynamic Working Time	2-4 hr	~4 hr
Set Time	~ 4 hr (initial)	~24 hr
Density (wet unit weight)	124 lbs/ft^3 1986 kg/m^3	129 lbs/ft^3 2066 kg/m^3
Bleed water	None	None
Segregation	None	None
Maximum particle size ASTM C 637 quartz sand	1 mm maximum	1 mm maximum
Cured Properties		
Compressive Strength		
3 days	760 psi 5.24 MPa	TBD
7 day	1047 psi 7.22 MPa	
28 days	psi	
Adiabatic temperature rise	34°C	34°C



(a) (b) (c)

(d) (e) (f)

Figure 10. Mixing evaluation (a and b) recirculating loop pump test (c), field static gel time test (d), semi-adiabatic heat generation (temperature rise) test (e) and mock-up vessel flow evaluation (f).

P-Reactor ISD

On November 18 and 22, 2010, 37.4 and 53.2 cubic meters (48.9 and 69.6 cubic yards), respectively, of the calcium sulfo-aluminate grout were pumped into the P-Reactor Vessel at the SRS. The batching operation consisted of two concurrently operated 1 cubic meter paddle mixers. Pre-blended reagents were delivered to the mixers in super sacks, (cement, fly ash, solid admixtures, and sand) via forklifts. Water and a liquid high range water reducer were metered into the mixing vessel. The grout was pumped from each mixing station to the reactor vessel entry ports which were located at three positions around the circumference of the reactor top. One line was used exclusively for filling one entry point. The other line had a manifold that allowed the flow to be cycled between two entry points every 20 minutes. The top of the grout in P-Reactor Vessel after completion was approximately 16 inches from the top of the plenum. See Figure 11.

(a) (b)

(c) (d)

Figure 11. P-Reactor Vessel ISD.
(a) Grout production, (b) 2000 pounds of pre-blended grout delivered to P-Area in super sack, (c) view of reactor plenum with plastic containment hut and grout line, and (d) view of filled P-Reactor Vessel – looking into opening with grout level about 14 inches from top working surface.

CONCLUSIONS

The SRS P- and R-Reactor Facilities are undergoing an in-situ decommissioning process. Approximately 145, 265 cubic meters (190,000 cubic yards) of structural fill material has been placed in the Disassembly Basins and in the -40 and -20 levels of these facilities. The ISD process for the entire 105-P and 105-R reactor facilities requires approximately 250,000 cubic yards (191,140 cubic meters) of grout and approximately 3,900 cubic yards (2,989 cubic meters) of structural concrete which will be placed over about an eighteen month period to meet the accelerated schedule ISD schedule.

Portland cement-based flowable grouts for bulk filling, underwater placement, and specialty light weight placements were developed by SRNL researchers. These materials were designed to meet the requirements for mass pour structural fill, have a low carbon foot print (the amount of portland cement was limited), utilize by-product materials (Class F-fly ash). The grouts were produced by 1) two off-site ready mix plants and 2) two on-site batch plants set up in P-Area. Placement was performed by 1) site D&D work force and 2) Baker Construction, Inc. and 3) Gibson Pressure Grouting, Inc, Smyrna, GA.

The ISD process was also applied to the SRS P- Reactor Vessel. A flowable calcium sulfo-aluminate grout was designed by SRNL for the unique material and placement requirements. Filling the P-Reactor vessel was completed on November 22, 2010. The calcium sulfo-aluminate grout was pre-blended off site by Gibson's Pressure Grouting, Inc. The dry reagents and aggregate blend was mixed with water and a HRWR at the 105 P-Building and pumped into the reactor vessel through three 2- inch grout hoses. The R-Reactor Vessel is scheduled to be filled with a portland cement-based structural fill (the same material used for the majority of the SRS reactor ISD) in December, 2010.

A flowable magnesium potassium phosphate grout was also developed as a potential reactor vessel fill material but was not deployed. This grout system has several interesting features, such as adhesion to metal surfaces, no shrinkage, and chemical stabilization of radionuclides. Other applications including D&D and are being pursued for this material.

REFERENCES

1. Langton, C. A., M. G. Serrato, J. K. Blankenship and W. B. Griffin, 2010. "Savannah River Site R-Reactor Disassembly Basin In-Situ Decommissioning", Waste Management Symposium, 2010, March 7 to 11, Phoenix AZ.

2. Engineering Evaluation/Cost Analysis for the Grouting of the R-Reactor Disassembly Basin at the Savannah River Site, DOE/EE/CA-001, May 2002.

2. Engineering Modification Traveler - ACP Baseline Technical Requirements for 105-R Reactor Disassembly Basin, Savannah River Nuclear Solutions, LLC, Savannah River Site, Aiken, SC 29808.

3. Serrato and C. A. Langton, 2009. 105-R Reactor Disassembly Basin Grout Placement Strategy, SRNL-TR-2009-00157, Revision 1, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

4. Vrettos, 2010, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

5. Wiersma, B. J., M. G. Serrato, and C. A. Langton, 2010 / 2011. "Assessment of the Potential for Hydrogen Generation During Deactivation and Decommissioning of the Reactor Vessels at the Savannah River Site", Paper for WM Symposium 2011, Phoenix AZ.

6. Wiersma B. J., 2010. "Assessment of Potential for Hydrogen Generation During Grouting Operations in the R- and P-Reactor Vessels, SRNL-STI-2009-00639, Revision 2, May 2010, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

7. Bibler, N. E. and M. M. Reigel, 2010. "Radiolytic Production of Hydrogen from Grout Containing Organic Admixtures Used in Decommissioning R-Reactor Vessel, SRNL-TR-2010-00262, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

8. Singh, D., 2010. "Final Report on Ceramicrete Grout Evaluation for the SRS Reactor Vessel Filling", December 2009. Argonne National Laboratory, Argonne, IL 60439.

9. Stefanko, D. B. and C. A. Langton, 2010. "Magnesium Potassium Phosphate Grout for P-reactor Vessel In-situ Decommissioning", SRNL-STI-2010-00333, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

10. Langton, C. A., and D. B. Stefanko, 2010, "Calcium Sulfo-aluminate Cement-Based Grout for Reactor Vessel ISD," SRNL-STI-2010-427, Draft, July 2010, Savannah River National Laboratory, Savannah River Site, Aiken, SC 29808.

ACKNOWLEDGEMENTS

The authors acknowledge W. Pope, W. Mhyre, A. Isherwood, N. Schramek, URS Washington Group Quality and Testing Division, who provided technical assistance and laboratory facilities for conducting a large portion of this work. The authors also acknowledge Eric Thompson, Dennis Bolye, and Don Gibson for technical support and use of the Gibson Pressure Grouting Services, Inc. facility for performing the reactor vessel scale-up testing.

This paper was prepared in conjunction with work accomplished at the Savannah River National Laboratory, Savannah River Nuclear Solutions, LLC, under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

DISCLAIMER