Technical Review of Documents Related to Tank 12H Grout Formulations, Grout Testing, Procedures, and Grouting Operations at the H-Area Tank Farm at Savannah River Site [Supplement to Technical Review Report on Tank 16H and 12H (ML16231A444)]

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General Grout Documents Reviewed:

1. C-ESR-G-00003. Waltz, R.S. "SRS High-Level Waste Tank Crack and Leak Information." Revision 13. Aiken, South Carolina: Savannah River Remediation, LLC. 26 October 2015. [ADAMS Accession No. ML14079A609]
2. C-SPP-Z-00012. "Vault 4 Clean Cap Grout." Revision 1. Aiken, South Carolina: Savannah River Remediation, LLC. March 2014. [ADAMS Accession No. ML16117A359]
3. SDDR No. 13182. "Supplier Deviation Disposition Request No. 13182 (Slag Cement not Meeting ASTM C989, Grade 100)." Aiken, South Carolina: Savannah River Site. June 2015. [ADAMS Accession No. ML16119A339]
4. SREL Doc. R-21-0001. Seaman et al. "Aqueous and Solid Phase Characterization of Potential Tank Fill Materials." Aiken, South Carolina: Savannah River Ecology Laboratory. August 20, 2020. [ADAMS Accession No. ML20303A339]
5. SRR-CWDA-2012-00051. Layton, M. "Critical Assumptions in the Tank Farm Operational Closure Documentation Regarding Waste Tank Internal Configurations." Revision 2. Aiken, South Carolina: Savannah River Remediation, LLC. January 2016. [ADAMS Accession No. ML13078A206].
6. SRR-CWDA-2017-00015. "Consolidated General Closure Plan for F-Area and H-Area Waste Tank Systems." Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. February 2017. [ADAMS Accession No. ML20279A784]
7. SRR-CWDA-2020-00052. Romanowski, L. "Follow-Up to Tanks 12H and 16H Grouting Operations Document Request in Support of U.S. Nuclear Regulatory Commission F and H Area Tank Farms Monitoring Activities (Memo to A. White of U.S. DOE)." Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. June 10, 2020. [ADAMS Accession No. ML20279A785]
8. SRR-CWDA-2020-00058. Romanowski, L. "Type I Waste Tanks Dehumidification System Heating and Ventilation Ductwork [From Dwg. # W146593]." Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. July 8, 2020. [ADAMS Accession No. ML20279A786]
9. SRR-CWDA-2020-00061. Flach, G.P. "Memorandum: Application of Characterization of the Aqueous and Solid Phase Chemistry of Closure Grouts." Revision 0. Aiken, South Carolina: Savannah River Remediation. August 25, 2020. [ADAMS Accession No. ML20303A345]

10. VSL-14R3330-1. Papathanassiu, A.E. et al. “Saltstone Clean Cap Grout Assessment (Final Report).” Revision 0. Washington, DC: Vitreous State Laboratory, The Catholic University of America. March 2014. [ADAMS Accession No. ML20279A790]
11. VSL-15R3740-1. Gong, W. et al. “Investigation of Alternate Ground Granulated Blast Furnace Slag for the Saltstone Facility (Final Report).” Revision 0. Washington, DC: Vitreous State Laboratory, The Catholic University of America. August 26, 2015. [ADAMS Accession No. ML16117A355]

<u>Tank 12H Documents Reviewed</u>:

1. HTF-SKM-2015-00010. “Tank 12 Flush & Grout Fill Configuration Intact Coils [WO] 1337683-31 (2 Sheets).” Revision B. Closure Engineering, Aiken, South Carolina: Savannah River Site. October 28, 2015. [ADAMS Accession No. ML20279A781]
2. HTF-SKM-2015-00021. “Tank 12 Grout Placement Plan – Sketch 1 (Associated with WO 01337683-33).” Revision 0. Aiken, South Carolina: Savannah River Site. 2015. [ADAMS Accession No. ML20279A782]
3. SRR-CWDA-2015-00074. “Addendum to the Industrial Wastewater Closure Module for Liquid Waste Tank 12H H-Area Tank Farm, Savannah River Site, SRR-CWDA-2014-00086, Revision 0, May 2015.” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. October 2015. [ADAMS Accession No. ML15294A364]
4. SRR-CWDA-2016-00068. “Tank 12 Final Configuration Report for H-Tank Farm at the Savannah River Site.” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. December 2016. [ADAMS Accession No. ML18235A409]
5. SRR-CWDA-2018-00047. “Savannah River Site F and H Area Tank Farms, NRC Onsite Observation Visit: *Tank 12 Grouting Calendar (Slide 21)*.” Revision 1. Aiken, South Carolina: Savannah River Remediation, LLC. 13–14 August 2018. [ADAMS Accession No. ML18247A080]
6. SRR-LWE-2014-00162. Voegtlen, R.O. “Video Inspection Plan for Tank 12 During Tank Grouting Activities (Interoffice Memorandum).” Revision 0. Aiken, South Carolina: Savannah River Remediation. February 12, 2015. [ADAMS Accession No. ML22056A507]
7. SRR-LWE-2016-00020. Voegtlen, R.O. “Tank 12 Grout Cracks under Riser 1.” Revision 0. Aiken, South Carolina: Savannah River Remediation. February 2016. [ADAMS Accession No. ML22056A508]
8. SRR-LWE-2016-00036. Voegtlen, R.O. “Tank 12 Final Configuration Report Inputs.” Revision 2. Aiken, South Carolina: Savannah River Site. December 2016. [ADAMS Accession No. ML20279A787]
9. SRR-TCR-2016-00007. Davis, B. “Tank 12 Grouting Liquid Spill Lessons Learned.” Aiken, South Carolina: Savannah River Remediation, LLC. May 9, 2016. [ADAMS Accession No. ML20279A788]
10. WO 01337683-31. Alexander, O. “TK.12 Flush & Grout Intact Chromate Cooling Coils.” Revision 1. November 2, 2015. [ADAMS Accession No. ML20279A791]
11. WO 01337683-31-A. “Attachment ‘A’ – Tank 12 Coil Flushing Spreadsheet.” [ADAMS Accession No. ML20279A792]
12. WO 01337683-31-F. “Attachment F – Coil Grout Spreadsheet.” [ADAMS Accession No. ML20279A794]
13. WO 01337683-33. Patton, G.W. “Placement of Bulk Fill Grout (Tank 12 Work Order).” Revision 2. [ADAMS Accession No. ML20279A795]
14. WO 01337683-33-A. “Attachment A – Tank 12 Tremie Installation Steps.” [ADAMS Accession No. ML20279A796]

15. WO 01337683-33-B. “Attachment B – Tank 12 Cleaning/Pigging of Slickline.” [ADAMS Accession No. ML20279A797]
16. WO 01337683-50. Alexander, O. “TK12 Grout Failed Coils.” August 12, 2015. [ADAMS Accession No. ML20279A798]
17. WO 01337683-51. Patton, G.W. “TK 12 Closure Constr Perform Equipment Grouting.” [ADAMS Accession No. ML20279A799]

<u>Tank 16H Documents Reviewed:</u>

1. 2015-NCR-15-WHC-0008. Redwood, A.R. “Nonconformance Report No. 2015-NCR-15-WHC-0008.” Aiken, South Carolina. June 29, 2015. [ADAMS Accession No. ML20302A273]
2. 2015-NCR-15-WHC-0013. Redwood, A.R. “Nonconformance Report No. 2015-NCR-15-WHC-0013.” Aiken, South Carolina. October 20, 2015. [ADAMS Accession No. ML20302A274]
3. HTF-SKM-2014-00031. “Tank 16 – Type II – 85’ DIA Grout Placement Plan.” Revision A. Aiken, South Carolina: Savannah River Site. 2015. [ADAMS Accession No. ML22056A511]
4. SDDR No. 13307. Ganguly, A. “Supplier Deviation Disposition Request No. 13307 (Bleeding of Concrete).” Aiken, South Carolina: Savannah River Site. October 28, 2015. [ADAMS Accession No. ML20279A783]
5. SRR-CWDA-2014-00102. “Disposal of Cooling Coil Grouting Liquid Within Tank 16 (Interoffice Memorandum from M.H. Layton to J. Rush).” Revision 0. Aiken, South Carolina: Savannah River Remediation. 20 November 2014. [ADAMS Accession No. ML22056A506]
6. SRR-CWDA-2015-00100. “Evaluation of the Use of an Alternative Tank 16 Fill Grout (Per Specification C-SPP-Z-00012) (Interoffice Memorandum to G.C. Arthur from M.H. Layton).” Revision 2. Aiken, South Carolina: Savannah River Remediation, LLC. September 1, 2015. [ADAMS Accession No. ML16119A341]
7. SRR-CWDA-2015-00160. “Evaluation of the Performance Assessment Impact of Using an Alternative Fill Grout in the H-Area Tank Farm. (Interoffice Memorandum to G.C. Arthur from M.H. Layton).” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. January 4, 2016. [ADAMS Accession No. ML16131A229)
8. SRR-CWDA-2022-00014. Mangold, J.E. “Dataset for [Tank 16 Clean Cap Grout] Tank 12 CLSM [sic] Modeling in GoldSim (Interoffice Memorandum).” Revision 0. Aiken, South Carolina: Savannah River Remediation. February 24, 2022. [ADAMS Accession No. ML23223A112]
9. SRR-TCR-2015-00024. Davis, B. “Tank 16 Grouting Lessons Learned (Memo).” Aiken, South Carolina: Savannah River Remediation, LLC. January 27, 2016. [ADAMS Accession No. ML16119A346]
10. USQ-HTF-2015-00635. “Use-As-Is Disposition of Non-Conformance Report (NCR) 2015-NCR-15-WHC-0008 ‘H Tank Farm Grout – Tank 16’ (Non-Conformance Tank 16 Grout Test Cylinders Deviation from Requirements of C-SPP-F-00055, Revision 4 ‘Furnishing and Delivery of Tank Closure Grout’ Technical Review Package),” Revision 0. September 2015. [ADAMS Accession No. ML22056A509]
11. USQ-HTF-2015-00686. “Use-As-Is Disposition of Non-Conformance Report (NCR) 2015-NCR-15-WHC-0013 ‘H Tank Farm Grout – Tank 16’ (Non-Conformance Tank 16 Grout Test Cylinders Deviation from Requirements of C-SPP-F-00055, Revision 4 ‘Furnishing and Delivery of Tank Closure Grout’ Technical Review Package),” Revision 0. October 2015. [ADAMS Accession No. ML22056A510]

12. USQ-HTF-2015-00706. Layton, M. “Supplier Deviation Disposition Request (SDDR) Number 13307 – Deviation from Specification C-SPP-F-00055, Revision 4 (Technical Review Package).” Revision 0. Place. October 2015. [ADAMS Accession No. ML20279A789]
13. WO 01324150-64. Fail, J.A. “TK CLOS & REG CN TO PERFORM GROUT PREP/GROUT PLACEMENT TK 16.” Revision 0. August 22, 2014. [ADAMS Accession No. ML16119A351]

NRC Technical Review

This technical review report updates a 2020 report focused mainly on Tank 12H grouting operations (ADAMS Accession No. ML20296A550). Although the focus of this report is on Tank 12H grouting, key findings from previous technical reviews, including those of Tank 16H grouting operations are also included. Changes to ML20296A550 are marked with vertical lines in the left margin. Summaries of the primary documents listed above, which are related to Savannah River Site (SRS) Tank Farm grouting, are provided in Appendix A. Technical reviews of the grout-related documents listed above, as well as reports that NRC reviewed previously (ADAMS Accession No. ML16231A444), are the basis for NRC's evaluation of SRS Tanks 12H (and 16H) grouting operations and final configuration, and Tanks 12H (and 16H) grouting lessons learned, discussed next.

The staff coordinated with the State of South Carolina Department of Health and Environmental Control (DHEC) to identify areas of grout operations to focus on as they have nearly constant oversight of tank grouting operations. The staff inquired as to whether there were incidents or abnormal situations during the grouting that resulted in variance from procedure (ADAMS Accession No. ML16111B174).

Evaluation

Tank Grout Formulation, Testing, Placement and Performance

Many of NRC staff's concerns about the waste tank grout formulation that resulted from the original technical review of Tank 18F and 19F grouting and subsequent review of Tank 5F, 6F, 12H and 16H grouting operations remain at the time of this writing. This technical review, which is focused on Tanks 12H and 16H grouting operations and grouting lessons learned, summarizes remaining NRC staff recommendations from prior technical review reports and accounts for new information or changes to DOE's approaches for Tank 12H and 16H. To fill the primaries and annuli of Tank 12H, DOE selected the same LP#8-016 reducing tank grout that had been used previously to fill Tanks 5F, 6F, 16H, 18F, and 19F (C-SPP-F-00055, Attachment 5.5). The following discussion addresses tank grout specifications and testing, grout placement, flowability and mounding, bleed-water segregation, cracking, and occurrences of groundwater in-leakage.

Grout Specifications and Testing

The tank grout specification for Tanks 5F, 6F, 12H, and 16H (C-SPP-F-00055, Revision 4) differed from that of Tanks 18F and 19F (C-SPP-F-00055, Revision 2) in that a greater slump flow range was specified to enhance grout flowability in tanks containing cooling coils (Table 1). Higher slump flow was achieved by increasing the dose of high-range water-reducer ADVA Cast 575 [W.R. Grace & Co., Cambridge, Massachusetts) to 1.18 to 1.2 liters (L) (40 or 41.25 fluid ounces (oz)] per cubic yard[1] (ADAMS Accession No. ML13267A452; SRR-CWDA-2013-00026, Attachments 3 and 4); however, 1.18 L per cubic yard (40 fluid oz per cubic yard) is the maximum amount allowed by the specification (C-SPP-F-00055, Revision 4, Attachment 5.5). The viscosity modifying admixture (VMA) EXP 958 dosage has not increased with the dosage of ADVA® Cast 575, even though VMAs are used to counter-balance use of high-range water-reducers that can otherwise lead to excessive bleed-water segregation. Experimental work conducted to design a clean cap grout for the Saltstone Disposal Facility (also used in

[1] Note that 1 cubic yard is equivalent to 0.76 cubic meter.

Table 1. Evolution of Admixture Dosages Used to Batch Tank Grout

<table>
<tr><td rowspan="3">Admixture</td><td colspan="7">Dose in Fluid Ounces per 8-cubic-yard Batch</td></tr>
<tr><td rowspan="2">Procurement Specification</td><td rowspan="2">Tank 5F</td><td rowspan="2">Tank 6F</td><td rowspan="2">Tank 12H</td><td rowspan="2">Tank 16H</td><td rowspan="2">Tank 18F</td><td rowspan="2">Tank 19F</td></tr>
<tr></tr>
<tr><td>ADVA Cast 575</td><td>80–320</td><td colspan="2">320</td><td>320–330</td><td>330</td><td colspan="2">160</td></tr>
<tr><td>EXP 958</td><td>Up to 330</td><td colspan="6">330</td></tr>
<tr><td>RECOVER</td><td>As Required</td><td colspan="2">50–60</td><td>50–70</td><td>30–60</td><td colspan="2">30</td></tr>
</table>

1 fluid ounce = 30 ml
1 cubic yard = 0.76 cubic meter

Tank 16H) found that use of ADVA Cast 575 in this formula significantly increased bleed-water production and rapid segregation of most of the grout solids from the liquid mass (VSL-14R3330-1). This observation may explain similar behavior of reducing tank grout from which bleed water separates to rapidly flow downgradient into pools at the tank perimeter during grouting operations. RECOVER is a hydration stabilizer added to the reducing tank grout mix at the batch plant or later onsite. The total volume of RECOVER added to the mix is that deemed necessary to delay grout setting; 1.5 L (50.7 fluid oz) of RECOVER per 8 cubic yards was added to the grout mix at the Argos batch plant. Any additional RECOVER used was added onsite (up to a total of 2.0 L or 70 fluid oz per 8 cubic yards), with the volume based on expert judgement related to ambient temperature, humidity, travel time, operational conditions, and visual observation of previous batches (ADAMS Accession Nos. ML18311A184 and ML22131A348).

By April 2015, it had become known to DOE that Holcim Grade 100 slag would soon cease to be available (SRR-LWE-2015-00032; SRR-CWDA-2016-00068). DOE began preparing to switch to a different source for ground granulated blast furnace slag cement in the reducing tank grout formulation in part by contracting-out a study of slag alternatives to Vitreous State Laboratory at The Catholic University of America. Based upon these test results, Lehigh Grade 120 slag was recommended for use (VSL-15R3740-1) by August 2015. Grade 120 slag was evaluated by DOE and its use in reducing tank grout was determined to be consistent with the inputs to and assumptions of the PA (UWMQE No. SRR-CWDA-2015-00088, SRR-CWDA-2015-00057). The grout specification (C-SPP-F-00055) was subsequently revised (Revision 4) to allow use of either Lehigh Grade 100 or Lehigh Grade 120 slag cement. Work order (WO) 01337683-33 addressed grout preparations for bulk fill tank grout. It is notable that Lehigh Grade 100 slag cement, which may be used in reducing tank grout per the revised grout specification, has not been put through the same set of tests as other slag alternatives (VSL-15R3740-1). Holcim's discontinued Grade 100 slag cement was shown to have a smaller mean grain size (13 μm ≤ d_{50} ≤ 16.05 μm; VSL-14R3330-1, VSL-15R3740-1) than Lehigh's Grade 120 slag (d_{50} ~18.47 μm; VSL-15R3740-1), and Holcim's discontinued Grade 100 slag had higher sulfide content than Lehigh's Grade 120 slag (VSL-15R3740-1). Substituting a generic Grade 120 slag for Holcim's Grade 100 slag was hypothesized to result in a higher compressive strength reducing tank grout at 28 days due to an assumed enhanced surface area (i.e., smaller particle size) and reactivity (VSL-15R3740-1; ADAMS Accession No. ML16231A444), but instead, Grade 100 slag tank grout placed into Tank 16H had a higher compressive strength than did Grade 120 slag tank grout placed into Tank 12H. The authors of these test reports did not dwell on their unanticipated finding that Holcim's Grade 100 slag may have had a finer mean diameter and enhanced chemical reactivity compared to the Grade 120 slags they tested for DOE. The impact of slag particle size variability on compressive strength, hydraulic conductivity, and chemical reactivity of the reducing tank grout is uncertain, as is the extent to which slag particle size from a given slag manufacturer varies with time.

The Argos batch plant used the remaining Grade 100 slag on January 19, 2016, to formulate initial batches of Tank 12H reducing grout (ADAMS Accession No. ML22131A348, response to Q2) before switching to use of Grade 120 slag on the second day of grouting (i.e., on January 20, 2016), after the first ~163 cubic meters [~213 cubic yards or ~43,000 gallons (gal)] of Lift 1 had been placed (SRR-LWE-2016-00036; SRR-CWDA-2016-00068) by 20 trucks on the first day and seven additional trucks on the second day [ADAMS Accession Nos. ML16167A237 and ML18247A080 (Slide 21)]. For purposes of checking grout volume estimates, based upon these numbers, a concrete mixing truck delivered ~6 cubic meters (~7.9 cubic yards) of grout per truck, rather than 6.1 cubic meters (8 cubic yards). DOE explained in SRMC-CWDA-2023-00074 that the lower volume is due to subtraction of grout volumes associated with testing (see Appendix B Item 8). Further discussion of pre- and post-grouting grout volume estimates is provided later in NRC's evaluation of *Grout Transferability, Flowability and Mounding*.

The glass content of ground granulated blast furnace slag cement is important to performance and should not be less than 67 percent; slag having greater than 90 percent glass content offers the most satisfactory properties (Siddique and Kaur, 2012). CNWRA staff examined DOE's vendor-provided Holcim Grade 100 and Lehigh Grade 120 slags using X-ray Diffraction (Walter and Dinwiddie, 2020). Holcim's Grade 100 slag produced no XRD peaks because it consists of amorphous glassy particles, whereas Lehigh's Grade 120 slag indicated a degree of crystallinity; therefore, reducing grouts comprised of each slag may differ in important properties. Minerals fit to the Grade 120 slag spectra included pyrophyllite, periclase, and nacrite. Some underfit peaks of Grade 120 slag may be clays; they did not fit minerals in the database. Reduced-sulfur-bearing minerals were not identified in the Grade 120 slag samples, although the detection limit is higher than would be observed for reduced sulfur-bearing minerals based on their expected abundance. Crystalline slag forms are not typically used as cementitious materials because they are not as chemically reactive as glassy slag.
Although NRC previously concluded that switching from Holcim Grade 100 to Lehigh Grade 120 slag was likely beneficial with respect to the chemical performance of grout placed in Tank 12H due to anticipated higher reducing capacity (ADAMS Accession No. ML16231A444), the effect of slag Grade on chemical reactivity and saturated hydraulic conductivity is uncertain. NRC staff will continue to monitor the impact of slag Grade on chemical performance of tank grout.

CNWRA performed grout water-conditioning experiments through 2020 (Walter and Dinwiddie, 2017; 2019; 2020; 2021). The laboratory-based experimental work focused on how reducing tank grout made with either Holcim's Grade 100 or Lehigh's Grade 120 GGBFS cement affects the dissolved oxygen concentration, pH, and oxidation–reduction potential (E_h) of synthetic groundwater because these parameters can affect the release of radionuclides from residual waste in grouted tanks. For the E_h of water seeping through tank grout to diminish to a value of approximately −470 mV as projected in some of DOE's PA modeling (e.g., SRR-CWDA-2010-00128) the dissolved oxygen concentration must be reduced to low levels at which redox couples other than O_2–H_2O control E_h. Shallow groundwater at the SRS has dissolved oxygen concentrations of 1 to 9 mg/L [1 to 9 ppm] (WSRC-RP-92-450). To attain the low E_h conditions assumed in PA modeling, dissolved oxygen must be removed from infiltrating groundwater by reaction with reductants in the tank grout. Sulfide content analyses of reducing tank grout ingredients and tank grout specimens were performed by Walter and Dinwiddie (2021) because sulfide is expected to be the primary reducing agent in tank grout. The sulfide content of fine aggregate (ASTM C33 sand by South Carolina Minerals, Inc. of North Augusta, South Carolina), ordinary Portland cement (Type I/II, ASTM C150 by Holcim US, Inc. of Birmingham, Alabama), and Class F fly ash (ASTM C618 by SEFA Group, Inc. of Lexington, South Carolina) used to produce reducing tank grout were below the 39 mg/kg detection limit of the SW-846 Method

9034 for total sulfide. Holcim's Grade 100 GGBFS sample had a sulfide content of 10,300 mg/kg (~1 percent), whereas Lehigh's Grade 120 GGBFS sample had a sulfide content of 7,900 mg/kg (~0.79 percent). One sample of Grade 100 slag reducing grout (specimen cast in 2015 and removed from mold in 2018) had a sulfide content of 51.6 mg/kg while another from the same specimen had less than the detection limit, indicating a heterogeneous distribution. The sulfide content of three Grade 120 slag grout samples (cast on April 11, 2016, and removed from mold in 2020) ranged from 39.6 mg/kg (i.e., slightly above detection limit) to 98 mg/kg (ML21278A101). The expected sulfide content of the Grade 100 and Grade 120 slag grout samples would have been 660 and 500 mg/kg based on the weight fraction of GGBFS in the specimens. Thus, the sulfide contents of both Grades 100 and 120 slag grout samples were significantly depleted with respect to those expected based on the weight fraction of GGBFS used to prepare them, potentially indicating significant loss of sulfide during grout preparation or storage, or heterogeneity in the distribution of sulfide due to segregation during hydration (Walter and Dinwiddie, 2021). Any deficiency in grout sulfide content is expected to limit the reducing capacity of tank grout.

In CNWRA experiments using fresh, pulverized grout (representing best case conditions) the lowest E_h observed was −303 mV. Subsequently, in a 2019–2020 CNWRA experiment conducted with 24 ~1 cm^3 grout samples of reducing tank grout comprised of Lehigh's Grade 120 slag, freshly cut from the interior of a specimen cast in April 26, weighing 106 g, and mixed with 517 mL synthetic SRS groundwater, the minimum E_h achieved was only −30 mV with dissolved oxygen saturation of 0.34 percent. Based on previous experiments with individual components of the reducing tank grout, GGBFS is the only component that produces strongly reducing conditions (such as E_h on the order of −200 to −300 mV). CNWRA staff discussed its reducing tank grout water-conditioning test results with DOE contractors at a December 9, 2020, teleconference about experiments conducted by SREL and the CNWRA to support tank farm closure at SRS (ADAMS Accession No. ML21026A012). At this meeting, G. Flach (SRR) presented results of SREL research that indicated neither the high nor the low E_h endpoints assumed in PA modeling were achieved under realistic laboratory conditions (SREL Doc. R-21-0001; SRR-CWDA-2020-00061). NRC inquired about sulfide content and use of XANES or other methods to determine sulfide content. J. Seaman (SREL) indicated that they only looked at total sulfur in XRF and did not look at speciation. Based on CNWRA and SREL experiments with laboratory-prepared reducing grout specimens, it is unlikely that SRS reducing tank grout will produce stronger reducing conditions in infiltrating contact water.

Experimental work conducted to design a clean cap grout for use in the Saltstone Disposal Facility—a grout that was also used to complete filling Tank 16H—found that switching from use of Holcim Grade 100 to Lehigh Grade 120 slag in that formula led to increased bleed-water production (VSL-14R3330-1).

Although DOE's position has been that the saturated hydraulic conductivity of reducing tank grout would not be impacted by the change in slag Grade (SRR-CWDA-2015-00057), Grade 120 slag may produce a grout with lower saturated hydraulic conductivity than assumed in the HTF PA, which in turn may enhance rapid bypass of infiltrating water around the grout mass rather than through it. CNWRA staff found that synthetic saltstone waste-form simulant (which has the same cementitious material ratios as clean cap grout, but the former is mixed with a salt solution and dosed with radionuclides instead of mixed with water) leach experiments indicated this grout, when prepared with Lehigh Grade 120 slag instead of with Holcim Grade 100 slag, may have lower saturated hydraulic conductivity than anticipated by up to two orders of magnitude, which may have implications for this property of reducing tank grout, as well

(ADAMS Accession No. ML20289A873). These limited experimental results do not support a causative relationship between slag grade and saturated hydraulic conductivity. DOE should evaluate the saturated hydraulic conductivity of reducing tank grout made with Lehigh Grade 120 slag.

Similar to the concern NRC raised in the Tank 16H grouting TRR (ADAMS Accession No. ML16231A444), DOE used two different grouts to fill Tank 12H [163 cubic meters (213 cubic yards) of grout batched with Grade 100 slag on the bottom of the tank overlain by grout batched with Grade 120 slag]. Had DOE used only Lehigh Grade 120 slag to batch grout placed into Tank 12H, a more homogeneous monolith may have developed. NRC will follow-up with DOE concerning the likely increased uncertainty on performance that may be associated with use of two different grout formulations with potentially different hydraulic conductivities.

The HTF PA assumes that tank grout has adequate compressive strength [i.e., minimum of 13,800 kilopascals (kPa) (2,000 psi or 138 bars) at 28 days post-placement, per HTF PA Table 3.2-9 (SRR-CWDA-2010-00128)], to withstand the overburden load on each tank[2], thereby providing stability upon closure and a physical barrier to discourage intruders. Forty-one sets of seven test cylinders were prepared with Tank 12H grout, yielding 287 test cylinders. To confirm that the minimum assumed strength was achieved for grout placed into Tank 12H, DOE conducted compressive strength testing of 205 grout test cylinder specimens collected at the point of delivery and aged either 7 or 28 days (SRR-CWDA-2016-00068). Compressive strength of grouts made with slag is dependent on slag chemical composition (e.g., CaO content), the proportion of slag used in the grout mixture, slag particle size, and environmental conditions during hydration. The compressive strength of the Lehigh Grade 120 slag reducing tank grout was expected to be greater than the Holcim Grade 100 slag grout at 28 days (VSL-15R3740-1; ADAMS Accession No. ML16231A444); instead, it was weaker, likely due to the smaller mean grain size of the Holcim slag and larger surface-area-to-volume ratio.

Although all tested Tank 12H grout cylinder specimens had compressive strengths greater than the design 28-day compressive strength of 13,800 kPa (2,000 psi or 138 bars), the average 28-day compressive strength of Tank 12H tank grout was 16,400 kilopascal (kPa; 2,383 psi or 164 bars; SRR-LWE-2016-00036), which was less than the Tank 16H average of 19,200 kPa (2,788 psi or 192 bars; SRR-CWDA-2015-00159). Grout made with Lehigh Grade 120 slag, which CNWRA found to have a degree of crystallinity, may pozzolanically react, set up, and strengthen more slowly than the former tank grout made amorphous, glassy, Grade 100 slag, but additional testing beyond 28 days would be necessary to support this hypothesis. DOE indicated that none of the 82 untested cylinders of Tank 12H grout remain available at this time, so no additional compressive strength or saturated hydraulic conductivity testing can be performed with them (ADAMS Accession No. ML21026A012).

Notwithstanding the potential issues listed above, assuming grout performance and testing requirements are met, reducing tank grout comprised in part of Grade 120 slag likely will meet

[2] Although DOE indicates that the compressive strength of the tank grout is adequate to withstand the overburden load on each tank, it is not clear to NRC that the tank grout, which is not expected to be fully bonded to the tank and vault, would initially be relied on to accept the load of overlying surface materials, including an engineered cover system to be placed over the tank farms. The reinforced concrete vault will initially be relied on to withstand the overburden load on each tank until such time that the vault fails. When discussing site stability during the July 2015 onsite observation (ADAMS Accession No. ML15239A612), NRC similarly noted that a bounding structural analysis might consider the mass of the tank grout without the associated stiffness of a solid, grout-filled monolith, because the tank grout is not expected to create a solid monolith with the tank/vault given the potential for shrinkage and cracking.

PA assumptions for closure of Tank 12H (ADAMS Accession No. ML16231A444). Additional information about the impact of Grade 120 slag on chemical reactivity, compressive strength, and saturated hydraulic conductivity of the reducing tank grout would help reduce uncertainty in PA results.

Groundwater Conditioning via Interactions with Reducing Tank Grout

Following bulk waste removal from Tank 12H, residual waste was approximately 5,678 L (1,500 gal) in the heel of the primary, 1,514 L (400 gal) on cooling coils in the primary, and 114 L (30 gal) in the annulus (SRR-LWE-2014-00162). Although DOE performed waste-release experiments to study the solubility of Tank 12H key radionuclides under various chemical conditions, the results may not be representative of conditions expected in the waste zone for submerged tanks, such as Tank 12H. As discussed in NRC staff's Tank 12H waste-release TRR (ADAMS Accession No. ML19298A092), the targeted chemical conditions in the experiments (see column "Target Experimental Conditions" in Table 2) were inconsistent with the assumed chemical conditions for what is referred to as "Condition C" and "Condition D" in DOE's H-Area Tank Farm PA [see column "HTF PA (for Submerged Tanks such as Tank 12H)" in Table 2].

With respect to submerged (i.e., partially or fully in the saturated zone) tanks, such as Tank 12H, DOE assumes mixing between aquifer water primarily flowing horizontally through the tank grout and infiltrating groundwater primarily flowing vertically through the tank grout. Therefore, the initial chemistry of the water in contact with the waste zone is assumed to be less conditioned (i.e., higher E_h and lower *pH*) via its interactions with reducing tank grout compared to what is assumed for non-submerged tanks where groundwater primarily flows vertically through the overlying, reducing tank grout. After the reduction capacity of the tank grout is depleted, the chemistry of the waste zone transitions to a higher E_h, reflective of oxidized conditions. The assumed E_h for submerged tanks under oxidized conditions is expected to be lower than it would be for non-submerged tanks, owing to the lower oxidation–reduction potential of the groundwater aquifer compared to meteoric water flowing through the tank grout. Likewise, the *pH* of groundwater in contact with the waste zone of submerged tanks is assumed to be lower because it is less conditioned by the alkaline tank grout. The impact of the more moderate chemical conditions for submerged Tank 12H is potentially higher solubility of key radionuclides such as plutonium and technetium.

The key radionuclide contributing to dose in DOE's PA for Tank 12H is I-129. The PA assumes no solubility control for I-129. Although DOE does not take credit for solubility control to limit I-129 dose in its PAs, DOE does take credit for sorption of I-129 in cementitious materials.

Table 2. Assumed and Targeted Chemical Conditions in Submerged Tank 12H from Table 5 in NRC's Tank 12H Waste Release TRR (ADAMS Accession No. ML19298A092)

	Measured Quantity	HTF PA (for Submerged Tanks such as Tank 12H)	Target Experimental Conditions	Actual Experimental Conditions
Condition C (HTF PA) or RRII (Target)	pH	8.8	11.1	10.8 - 11.5
	E*h* (mV)	-310	-470	-71 to +205
Condition D (HTF PA) or ORII (Target)	pH	8.8	11.1	10.6
	E*h* (mV)	+360	+560	+340
ORIII	pH	9.2	9.2	9.2
	E*h* (mV)	+290	+680	+410

If DOE takes advantage of solubility control for I-129 for tank farm tanks in the future, a better understanding of the expected evolution of the geochemical conditions in the waste zone would be needed because I-129 solubility could be sensitive to E_h and pH. Additional information to support the expected solubility of I-129 under the assumed geochemical conditions would also be needed (e.g., the targeted E_h and pH in the Tank 12H waste-release experiments were inconsistent with the reference case conditions assumed in DOE's H-Tank Farm PA; ADAMS Accession No. ML19298A092).

Additionally, the results of DOE's waste-release experiments show that the H-Tank Farm PA likely under-predicted the solubility of other key radionuclides for the tank farm by orders of magnitude (e.g., Pu and Tc). A comparison of the Tank 18F and Tank 12H waste-release experiments also suggest that there is significant variability in key radionuclide mobility from tank to tank; most notably, the observed Pu concentrations in Tank 18F were orders of magnitude higher than in Tank 12H and those assumed in the F-Tank Farm PA. Therefore, tank grout performance and related impacts on waste release may be more risk significant for other H-Tank Farm tanks with unknown tank waste geochemistry and uncertain final inventories. Without sufficient understanding of the controls on aqueous phase concentrations in the waste zones of tank farm tanks, it would be difficult to extrapolate the results of the Tank 18F and Tank 12H waste-release experiments to other tanks.

Grout Placement

Grouting operations at Tank 12H began on January 19, 2016, and were completed on May 2, 2016 (SRR-LWE-2016-00036; SRR-CWDA-2016-00068; SRR-CWDA-2018-00047). Tank primary grouting began on January 19, 2016, and ended on March 7, 2016 (SRR-LWE-2016-00036; SRR-CWDA-2018-00047; ADAMS Accession No. ML20280A286). Annulus grouting began on February 8 and ended on March 1, 2016 (SRR-LWE-2016-00036; SRR-CWDA-2018-00047; ADAMS Accession No. ML20280A286). Failed cooling coil grouting began on January 26 and ended on January 29, 2016 (ADAMS Accession No. ML20280A286). Intact cooling coil grouting began on March 4, 2016, according to WO 1337683-31-F, continued on March 17, 2016 (SRR-CWDA-2018-00047; HTF-SKM-2015-00010; WO 1337683-31-F, ADAMS Accession No. ML22131A348, response to Q18) and ended on March 21, 2016 (SRR-LWE-2016-00036; SRR-CWDA-2018-00047; HTF-SKM-2015-00010; WO 1337683-31-F, ADAMS Accession No. ML22131A348, response to Q18). Riser grouting began[3] on March 31, 2016 (SRR-LWE-2016-00036), or April 5, 2016 (SRR-CWDA-2018-00047; ADAMS Accession No. ML20280A286) and ended[4] on April 23, 2016 (ADAMS Accession No. ML20280A286), or April 27, 2016 (SRR-LWE-2016-00036; SRR-CWDA-2016-00068; SRR-CWDA-2018-00047). Finally, a spray chamber located above Riser 5 of Tank 12H was grouted on May 2, 2016 (SRR-CWDA-2016-00068).

NRC reviewed DOE's Tank 16H grouting operations lessons learned document, which included the recommendation to devise a grout placement sequence/lift height plan based on real grout data for set-up time, specific gravity, etc., instead of on bounding values to potentially provide

[3] The Tank 12 Grouting Calendar and grouting operations video provided by DOE "Riser 3, 4, N, W, fills" indicates that riser grouting began on April 5, 2016 (ADAMS Accession No. ML20280A286), which contradicts the SRR-LWE-2016-00036–given date of March 31, 2016—a date for which no video was provided.

[4] Final grouting operations video provided by DOE, i.e., "Riser Center, 5, 8, 6," has a date of April 23, 2016 (ADAMS Accession No. ML20280A286); no video was provided of riser grouting that may have occurred on April 27, 2016.

more placement flexibility. For Tank 12H, a structural analysis was performed to estimate the stresses that would be applied to the wall of the primary during grout placement (T-CLC-F-00496) but given that Tank 12H grouting began within months of Tank 16H grouting, the Tank 12H structural analysis likely assumed bounding values. Real grout data should be used during future Tank 15 structural analyses for grout placement. Based on the results, the following lift height limits were implemented to prevent tank wall failure:

1. Height of annulus grout above primary grout was limited to ≤1.8 m (6 ft).
2. Height of primary grout above annulus grout was limited to ≤2.4 m (8 ft) (SRR-CWDA-2016-00068).

A 9-lift grout-placement sequence was devised to cycle between grouting the tank primary and the annulus to remain within the calculated lift-height limits (SRR-LWE-2016-00036). Tank interior bulk fill was comprised of Lifts 1, 4, 6, and 8 (SRR-LWE-2016-00036). Annulus grout was comprised of Lifts 2, 3, 5, 7, and 9 (SRR-CWDA-2016-00068). A 0.6-m- (2-ft)-thick Lift 1 was placed in the primary first to eliminate tank-floating concerns and support the in-tank carbon steel cooling coils (SRR-CWDA-2016-00068). Due to groundwater ingress into the annulus, however, placement of Lift 2 in the annulus was delayed throughout the first week of February 2016 until Lift 4 in the primary had also been poured. Under continuous placement conditions, the grout discharge rate into the tank primary and annulus ranged from 0.76 to 1.07 cubic meters per minute (1.0 to 1.4 cubic yards per minute) (RPT-5539-EG-0016), which is consistent with NRC staff notes that 6 to 7 minutes elapsed during grout placement from a single truck.

Grout Transferability, Flowability and Mounding

Type I tanks, such as Tanks 5F, 6F, and 12H, contain both vertical and horizontal cooling coils to cool waste, and 12 steel and concrete support columns. Cooling coils and support columns are obstructions that make it challenging to clean waste from the bottom of the tank and to grout the tank. More than 6.9 km (4.3 mi) of cooling coils are present in Tank 12H. To completely fill tanks that contain cooling coils and support columns with tank grout, DOE enhances tank grout flowability by specifying a higher range of desirable slump flow values (C-SPP-F-00055, Revision 4, Attachment 5.5), achieved solely using admixtures (i.e., high-range water reducer). Acceptable slump flow was obtained at the Argos batch plant and 30.3 L (8.0 gal) of water was withheld to allow further slump adjustments through water addition after grout was delivered to the site (per ASTM C94). During the October 2014 teleconference about Tanks 5F and 6F grouting operations (ADAMS Accession No. ML14330A037), NRC inquired about the process DOE used to reach the desired slump through use of water additions and admixtures. DOE explained that their contractors provided slump flow test results to the Argos batch plant in the morning after the first cement mixer trucks reach the site, so that the plant could modify slump through addition of admixtures at the batch plant without requiring water additions at the tank site. For Tank 12H and its annulus, DOE used 6 risers as grout entry points (Risers 1, 3, 5, and 8 in the tank primary, and the East and West Risers in the annulus (SRR-CWDA-2020-00052, Attachment 3). Reducing grout flowed over the waste material on the floor of the tank, stabilizing and immobilizing it (SRR-CWDA-2016-00068). Grout flowed around internal obstructions (cooling coils and support columns) without significant mounding (SRR-CWDA-2016-00068; SRR-LWE-2016-00036). During grouting operations, video cameras were also installed in Risers 1, 3, 5, and 8 in the tank primary, and the East and West Risers in the annulus to monitor (i) grouting of the tank primary, annulus, and abandoned equipment, (ii) tremies during grouting operations and disconnection, (iii) grout level based on landmarks/abandoned equipment, and (iv) discharge of line-clearing pigs (SRR-LWE-2014-00162). Camera inspections of the waste tank identified no significant issues with filling void space at the top of the tank due to mounding (SRR-LWE-2016-00036), and there was only a small deviation between pre-estimated and final calculated tank grout volumes (SRR-CWDA-2016-00068). Void volume estimates for grouting Tank 12H were documented in the final configuration report inputs (SRR-LWE-2016-00036). DOE estimated that 3,003 cubic meters (3,928 cubic yards) of grout would be required to fill a generic, empty Type I tank (U-CLC-G-00001), excluding riser volumes. For Tank 12H specifically, DOE estimated that its volume was 3,010 cubic meters (3,937 cubic yards), and that the volume of residual material remaining on the floor of the primary (Figure 1) and on cooling coils (Figure 2) totaled 7.2 cubic meters (9.4 cubic yards) (SRR-LWE-2016-00036; U-ESR-H-00125; M-CLC-H-03256). Accounting for the residual material volume, the final estimated Tank 12H grout volume (excluding risers) was 3,003 cubic meters (3,928 cubic yards). Based on design drawings, the estimated volume of grout that would be taken up by the primary risers and 4 spray chambers was 21 cubic meters (28 cubic yards) (SRR-LWE-2016-00036). DOE estimated that a grout volume of 422 cubic meters (552 cubic yards) would be required to fill a generic Type I tank annulus (U-CLC-G-00001). For the Tank 12H annulus, however, DOE estimated that its actual volume was 446 cubic meters (583 cubic yards), excluding risers. Based on design drawings, the estimated volume of grout needed to fill Tank 12H annulus risers was 17 cubic meters (22 cubic yards) (SRR-LWE-2016-00036; this report's Table 2 is augmented here as Table 3).

According to completed operations logs [i.e., Work Order (WO) 01337683-33], 2980 cubic meters (3,902 cubic yards) of grout were placed as bulk fill in the primary (2,970 cubic meters or 3,887 cubic yards) and primary risers (11 cubic meters or 15 cubic yards), and 477 cubic meters (624 cubic yards) of grout were placed as bulk fill in the annulus (469 cubic meters or 613 cubic yards) and annulus risers (8.4 cubic meters or 11 cubic yards), for a total of 3,460 cubic meters (4,526 cubic yards) (cf. SRR-LWE-2016-00036; Table 3).

The actual grout volume placed into the primary was calculated based upon the assumption that 486 trucks used to deliver grout to the primary each nominally contained 6.1 cubic meters (8 cubic yards) of grout (SRR-CWDA-2016-00068); Lift 1 data provided by DOE, however, suggests that mixer trucks may discharge only ~6.0 cubic meters (7.9 cubic yards) of grout in practice, which would imply that, at the low end, 2,935 cubic meters (3,839 cubic yards) was placed into the Tank 12H primary, a ~2.2 percent difference between the pre-estimate and the actual amount of grout placed.[5] Risers penetrating Tank 12H (SRR-CWDA-2020-00052, Attachment 1) were filled with grout to the bottom of the top riser cover/plate, above grade level (SRR-LWE-2016-00036), but during riser grouting, the amount of grout placed was little more than half the amount estimated (Table 3). DOE explained that some of the riser void volume was grouted during primary or annulus grouting, prior to formally beginning riser grouting, and that not all riser cover port plugs were removed from the risers, such that riser grout volumes were originally overestimated (SRR-LWE-2016-00036). Risers provide access points to the tank primary and annulus, and riser cover port plugs (see SRMC-CWDA-2023-00074, Attachment 4) provide shielding to workers from in-tank radiation and mercury inhalation. Riser cover port plugs were removed from risers as needed to install tremies to place grout, to remove excess liquid by pumping, and to grout in-riser equipment, but other riser cover port plugs remained in

[5] DOE explained in SRMC-CWDA-2023-00074 that the lower discharge volume was due to subtraction of grout volumes associated with testing rather than an inability to discharge the full volume of grout.

place for the duration of grouting operations, and thereby took up some riser volume that otherwise would have been filled with tank grout (SRR-LWE-2016-00036).

Figure 1. Residual WIR on the Floor of the Tank 12H Primary Appears Similar to Mud Cracks. Light Reflects off a Pool of Water beyond the Column in the Bottom Image. Date of Video: January 19, 2016.

The Tank 16H grout strategy indicated that having 8 to 10 cement mixer trucks in rotation was ideal (SRR-LWE-2014-00013), whereas the Tank 12H grout strategy later clarified that a grout delivery rate of 8 to 10 trucks per hour (SRR-LWE-2014-00147) was ideal. Cement mixer trucks took approximately one hour to complete the circuit from the Argos batch plant to H-area tank farm and return (ADAMS Accession No. ML22131A348, response to Q10). Eight to 10 trucks per hour converts to 49 to 61 cubic meters per hour (64 to 80 cubic yards per hour [assuming discharge of 6.1 cubic meters (8 cubic yards) of grout per truck], consistent with Section 3.6.1.2 of the procurement specification, which requires a sustained average delivery of 57 cubic meters per hour (74 cubic yards per hour) during an 8-hr workday (C-SPP-F-00055, Revision 4).

Figure 2. Residual WIR on cooling coils within the Tank 12H Primary. Date of Video: January 19, 2016.

Table 3. Estimated vs. Actual Grout Volumes Placed in Tank 12H

Tank 12H	Estimate (CY)	Actual (CY)	Difference (CY)
Tank 12H Primary w/o Risers	3927	3887	−40
Primary Risers (w/ 4 spray chambers)	28	15	−13
Tank 12H Primary + Primary Risers	**3955**	**3902**	**−53**
Tank 12H Annulus w/o Risers	583	613	30
Tank 12H Annulus Risers	22	11	−11
Tank 12H Annulus + Annulus Risers	**605**	**624**	**19**
Total Risers (Primary + Annulus)	**50**	**26**	**−24**
Total Tank 12H	**4560**	**4526**	**−34**

CY = cubic yards
1 cubic yard = 0.76 cubic meters

When NRC staff asked about the feasibility of establishing contractual obligations for the number of cement mixer trucks in rotation, DOE indicated that such contractual obligations would lead to significantly higher costs because it must compete with other customers for trucks (ADAMS Accession No. ML16167A237). Instead, DOE contractors worked with the Argos batch plant to schedule tank grouting during weeks when the plant can supply sufficient trucks to the tank closure effort (ADAMS Accession No. ML16167A237). DOE noted that while less than the optimal number of trucks were in rotation during Tank 12H grouting operations, no significant mounding issues occurred (ADAMS Accession No. ML16167A237).

Grout mounding may have been a less significant issue for Tank 12H than for Tank 16H in part because tank primary and annulus grouting operations took place during winter and early spring

(19 January–28 April 2016), instead of during high-temperature summer months. NRC has reviewed the Tank 16H grouting operations lessons learned document (SRR-TCR-2015-00024), which recommended that highly flowable clean cap grout be tested and evaluated to ensure that it meets tank farm PA requirements, so that if needed in the future, it can be used with confidence to again fill a tank primary or annulus between any mounds of reducing grout that may form and the tank ceiling. Additionally, the lessons learned document advised that grouting operations be planned around seasonal weather expectations, because high summer temperatures were thought to have resulted in the unusual mounding observed only in Tank 16H, to date. Ventilation introduces ambient outside air into the waste tanks during grouting operations, so external air temperatures may influence in-tank temperatures during grout hydration. To preserve maximum schedule flexibility, DOE should seek to understand why reducing tank grout placed into Tank 16H mounded excessively beneath tremies in the discharge zone, to minimize the likelihood of this phenomenon's recurrence during future grouting of other tanks. NRC recommends DOE monitor in-tank temperatures during grouting operations. Efforts to correlate ambient air temperatures, or alternatively, grout placement rates with the temporal occurrence of the mounding phenomenon may be informative. The Tank 16H lessons learned document ultimately noted that highly flowable clean cap grout could not be placed inside Tank 12H without obtaining pre-approval from SC DHEC.

The Tank 16H lessons learned document also addressed needs to (i) remove diversion valves from the grout slickline, because such use resulted in grout plugging and ineffective cleaning of the slickline, and (ii) develop a better method to ensure that the grout slickline is fully wetted/lubricated prior to grout introduction to minimize grout plugging (SRR-TCR-2015-00024). During an April 28, 2022, follow-up teleconference, DOE indicated that there are no plans to use diversion valves during tank closure operations in the future (ADAMS Accession No. ML22131A348, response to Q9).

During the final stages of placing Lift 8 grout into the Tank 12H primary on March 7, 2016, a liquid spill onto the tank top occurred when liquid that had accumulated in the primary backed-up into a spray chamber above tank level and emerged from the earth around Riser 7 (ADAMS Accession Nos. ML18311A184 and ML22131A348, response to Q23), which was not monitored by a camera (SRR-TCR-2016-00007). Riser 7 was not as well-sealed as other Tank 12H risers, and liquid/grout spilled from it onto the tank top and spread over a couple hundred square feet (ADAMS Accession No. ML22131A348, response to Q23). The spill was contained using spill kits and cleaned up (ADAMS Accession No. ML22131A348, response to Q23). Then Riser 7 was capped and grouted.

NRC staff reviewed the document "Tank 12 Grouting Liquid Spill Lessons Learned" (SRR-TCR-2016-00007). While this document does not explicitly describe the spill event that took place, it indirectly provides considerable information. First, 95-to-190 L (25-to-50-gal) of water per grouting day were introduced into the tank primary and annulus through the grouting slickline as it was being wetted in preparation for placing grout. Next, during the grouting of failed cooling coils, several thousand gallons of water were added to the tank primary. In addition to these planned water additions, segregation of bleed water from the grout mass is a third mechanism for liquid accumulation inside the tanks during grouting (ML16231A444).

The lessons learned document identified a number of factors that contributed to the liquid spill, including:

(i) 6 to 8 ft of spray chambers left in place inside risers that were a visual obstruction to cameras that would otherwise observe rising grout levels; everything appeared to be the same color and was difficult to interpret, which made it difficult to monitor liquid levels inside risers used to both grout the primary and monitor grouting activities;

(ii) Lack of an explicit grouting termination plan or plan to control riser liquid levels in the work order for filling the tank primary;

(iii) Lack of a grout spill plan in the work order that would explicitly call for intentionally locating spill kits near the active riser to minimize the impact and spread of any liquid spill;

(iv) Lack of an approved plan for mitigating free liquid in risers through addition of a dry grout mix to assimilate or absorb liquid;

(v) Schedule-driven grouting, especially after the failed cooling coils were grouted, did not allow sufficient time for free liquid to be absorbed during the grout's slow hydration process;

(vi) Lack of work orders for removing accumulated liquid from the risers via pumping;

(vii) Potential failure to evaluate the specific configuration and condition of individual risers that might increase their likelihood of causing spillage, so that work order plans could be adapted accordingly;

(viii) Video cameras being the only instruments used to monitor rising grout/liquid levels in risers, and

(ix) Cameras being placed only in four of the nine risers in the tank primary, so grout levels in risers could not always be monitored via video camera.

Recommendations from the lessons learned document included:

(i) Reevaluating the costs/benefits of removing spray chambers from risers so that they are not an obstruction to video-camera viewing;

(ii) Improving grouting work orders to better control and mitigate rising liquid/grout levels in risers and plan for quick, effective responses to liquid spills;

(iii) Evaluating alternatives for wetting grouting slicklines other than adding water to the tank;

(iv) Planning grouting operation schedules around the need to remove excess liquid from tanks, so that water is either absorbed, evaporated, or pumped out over the necessary period of time;

(v) Adapting work order development to account for actual field conditions of tank risers;

(vi) Reevaluating the costs/benefits of preparing all tank risers with a grout plate to allow insertion of video cameras that can monitor rising liquid levels inside all risers;

(vii) Evaluate the potential future use of other liquid level instruments in each riser that can sound an alarm when a threshold liquid level is exceeded.

Bleed-Water Segregation and Grout Impacts

During prior tank grouting operations, rapidly migrating dark water was observed to bleed from slowly flowing, light-colored grout lobes as grout flowed away from the discharge zones of Tanks 18F, 19F, 5F, 6F, and 16H. During review of Tank 12H grouting video footage that DOE provided of bulk tank and annulus grouting (ADAMS Accession No. ML20280A286), NRC staff observed bleed-water segregation of tank grout that could enhance shrinkage along the periphery (i.e., at the wall) of the tank and result in inhomogeneous material properties affecting water percolation patterns through the monolith. (Accession No. ML20280A286). NRC staff note the potential for bleed water to segregate from the grout mix during grout flow and distribution throughout the tank (see also VSL-14R3330-1, and its discussion of the bleed-water effects of use of ADVA Cast 575), whereby potentially higher water-to-cement-ratio grout is delivered to outlying portions of the tank, far from the discharge riser (ADAMS Accession No. ML16231A444). Dark water emerges from the free surfaces of freshly flowing, light-colored grout lobes: from their front edges, side edges, and top surfaces (Figure 3). Video cameras focused significant attention on the grout/tank wall interface (SRR-LWE-2014-00162) and

Figure 3. Photo of Bleed-Water Segregation Occurring in Grout Poured into the Tank 12H Primary. The Dark Outline Surrounding a Freshly Deposited Lobe of Grout is Segregated Water Separating from the Grout Mass. Date of Video: January 19, 2016.

recorded aqueous ponds forming at lower elevations near the tank perimeter, away from mounded grout located beneath the discharge riser (SRR-CWDA-2015-00170; ADAMS Accession No. ML16231A444). NRC staff found that bleed water was exuding from the bulk mass of flowing tank grout when it was being distributed throughout Tank 16H, and that this exudate increased the overall volume of water that collected in pools at the tank wall beyond the amount introduced as slickline and tremie lubricant[6] (ADAMS Accession No. ML16231A444). Exposed grout lying above pools of water will hydrate in a relatively dry microclimate, whereas grout submerged under standing water at the tank perimeter will hydrate in a saturated microclimate; because of this, grout properties are unlikely to be uniform (ADAMS Accession No. ML13127A291). Tank grout that hydrates and hardens in a subaqueous environment may have different properties relative to that forming subaerially; although it is not entirely clear what environment will produce higher-quality, better-performing grout (ADAMS Accession No. ML16231A444). NRC staff reviewed the Tank 16H lessons learned document (SRR-TCR-2015-

[6] During the July 28–29, 2015, onsite observation visit, DOE approximated that 18.9 to 26.5 L (5 to 7 gal) of water per day (quantity dependent on the length of the line) was used to lubricate the Tank 16H slicklines and tremies at the beginning of the day and then discharged into the primary or annulus.

00024), which had a recommendation to analyze data from Tank 16H grout testing to develop an acceptable, non-zero range for bleed-water production.

DOE discussed in the Tank 12H final configuration report how water tended to accumulate in low areas at the tank perimeter, rather than under discharge risers, such that grout was not directly placed into standing water (SRR-CWDA-2016-00068); this description is generally consistent with NRC staff's prior observations of grout placement and bleed-water segregation in other grouted tanks. DOE stated that water resting on the surface of underlying grout at the perimeter of the tanks is not expected to degrade cured grout properties (SRR-CWDA-2016-00068). DOE made the point that grout was not placed into standing water in Tank 12H because grout drop test results (RPT-5539-EG-0016) found a greater potential for bleed-water segregation to occur when grout is directly placed into aqueous pools (SRR-CWDA-2016-00068; SRR-LWE-2014-00147; ADAMS Accession No. ML16111B174). Residual pools of flush water present on the floor of the tank before grouting began were mapped so that those areas could be purposefully avoided during initial grouting of Tank 12H (ADAMS Accession No. ML16111B174).

Although DOE indicated in the Tank 12H grout strategy document that grout could generally be placed from a significant drop height through diffuse freefall (SRR-LWE-2014-00147; RPT-5539-EG-0016), it subsequently indicated that a tremie was always used during Tank 12H grouting operations to control grout placement (ADAMS Accession No. ML16167A237) and that tremies would continue to be used during future grouting operations (ADAMS Accession No. ML16167A237). DOE drops one 1.5 m (5 ft) section of tremie at a time into the tank as the grout level rises; DOE does not drop grout into the tank from full height. Because some freefalling grout could drop directly into pools of water, which would locally enhance bleed-water segregation, NRC thinks that use of tremies is a good practice to carefully control grout placement.

Groundwater in-leakage into submerged Tank 12H led to delays in grouting and/or need for mitigative measures such as pumped removal of groundwater to avoid grouting into areas of the tank containing standing water[7]. DOE has worked with the State to ensure that ventilation systems of sufficient capacity will remain operable at the time of grouting to avoid future problems with groundwater in-leakage for submerged tanks (ADAMS Accession No. ML22131A348, response to Q14). DOE should continue to ensure that grout does not drop into standing water, which could lead to detrimental impacts to grout quality, or should provide additional support that excess in-tank water does not locally degrade cured grout properties or negatively impact performance. NRC staff will continue to monitor the extent of bleed-water segregation that is visible during tank grouting operations and potential impacts to grout performance.

Grout Cracking

Within Lift 6 in the Tank 12H primary, several isolated cracks were observed to have formed in the grout below Riser 1 during the morning video camera inspection on February 22, 2016 (SRR-CWDA-2016-00068; SRR-LWE-2016-00020). The cracks were described as emanating in a circle from under Riser 1 near where pigs entered the tank (SRR-LWE-2016-00020). The longest crack was estimated to be <1 m (<3 ft) (SRR-CWDA-2016-00068). Grout was last placed through Riser 1 during the previous grout placement day, which was five days earlier on

[7] When grout is dropped into standing water, there is greater potential for bleed-water segregation to occur (RPT-5539-EG-0016).

February 17, 2016. DOE contractor staff speculated that the cracks would not extend deeper than the grout thickness poured during the prior workday [i.e., ≤0.6 m (≤2 ft)] (SRR-CWDA-2016-00068); however, this depends on the mechanism that caused the cracks to form (Dinwiddie et al., 2011). DOE indicated that the cracks in the grout appeared surficial and localized, and therefore they were expected to have minimal impact on system performance because they were thought to be unlikely to significantly increase the quantity of groundwater that would flow through the monolith to residual waste at the bottom of Tank 12H (SRR-LWE-2016-00020; SRR-LWE-2016-00036). In the final configuration report, no indication was given about the size range of the observed crack apertures. DOE stated that these cracks would not appreciably impact grout performance with respect to waste tank stability, flow through the tank, or the reducing capacity of the grout (SRR-CWDA-2010-00128; SRR-CWDA-2015-00074; SRR-LWE-2016-00036). Large-aperture cracks were previously observed to have formed in the annulus grout of Tank 16H, shortly after the grout had been placed. DOE could provide additional information, such as crack aperture, to assess the impact of crack formation on tank grout performance. Additionally, DOE should provide information about the mechanisms of crack formation, including thermal cracking, for all waste-stabilizing grout monoliths, including Tanks 12H and 16H to improve understanding of the nature and extent of cracking to assess the impact on performance. CNWRA experiments showed that dye-tracer slug tests performed on the NRC's intermediate-scale grout monolith indicated seven orders of magnitude in saturated hydraulic conductivity variation (Dinwiddie et al., 2013). Additionally, this grout monolith specimen featured slightly mounded grout on more than half its surface; a locally larger load was applied by the monolith on the topographically high side of the monolith, and a permeable crack or fault developed to accommodate movement of the mounded grout to the topographically low side of the monolith (Dinwiddie et al., 2013). Given the potential for thermal cracking of large, hydrating grout monoliths and the potential for high temperatures to cause mounding-related imbalanced loads that may induce development of through-going, subvertical faults in grout monoliths, NRC staff recommends DOE monitor in-tank temperatures during grouting operations.

Groundwater In-Leakage into Tank 12H

During a May 17, 2016, teleconference, NRC inquired whether DOE had placed constraints on grouting operations related to accumulation of water in tanks. DOE contractors responded that they use expert judgement to determine when and under what conditions grouting should proceed (ADAMS Accession No. ML16167A237).

Placement of Lifts 2 and 3 in the Tank 12H annulus was delayed (ADAMS Accession No. ML16111B174) until 8 February 2016 (SRR-CWDA-2016-00068), due to groundwater accumulation in the annulus (Figure 4) when the temporary ventilation system, which forced unheated air through the annulus, was shut off (ADAMS Accession No. ML16167A237). As expected, groundwater accumulated in the annulus faster when air was "pulled" under negative pressure than it did when it was "pushed" with positive pressure (ADAMS Accession No. ML16167A237 and SRR-LWE-2015-00048). DOE estimated that ~3,785 L (~1,000 gal) of groundwater was pumped out of the Tank 12H annulus (ADAMS Accession No. ML16167A237), reducing the water level to no more than 5 cm (2 in). Any standing water remaining in the annulus when grouting began likely would have enhanced bleed-water segregation in Lift 2 (cf. RPT-5539-EG-0016, Test 2), leaving an as-yet-unquantified impact on the saturated hydraulic conductivity of the bottom layer of grout (i.e., Lift 2) in the annulus (cf. SRNL-STI-2012-00576).

As tank grout placed into Tank 12H primary approached the tank roof and risers, liquid perched on the grout surface was observed from several risers (SRR-CWDA-2016-00068; SRR-LWE-2016-00036). DOE contractors initially speculated that the liquid may have been (i) the "hundreds of gallons of liquid (that) remained on the tank floor" when grouting of the primary

Figure 4. Groundwater In-Leakage in the Annulus, as viewed from the West Riser. Date of Video: January 19, 2016.

began, (ii) rainwater that intruded from riser openings, (iii) liquid used to lubricate the slicklines and tremies, and/or (iv) groundwater in-leakage at a rate of 18.9 L/hr (5 gal/hr) through a crack in the wall near the base of Riser 8 (SRR-LWE-2016-00036). Tank 12H is located entirely below the water table, allowing in-leakage to occur. DOE has also considered that some of the liquid perched on the grout surface could have been bleed water that segregated away from grout flow lobes, flowing to low spots near the tank wall (ADAMS Accession No. ML22131A348, response to Q13). DOE contractors pumped 4,500 L (1,200 gal) of liquid from seven of nine risers in the tank primary (i.e., Risers 1, 2, 5, 6, 7, 8, and Center; SRR-CWDA-2016-00068; SRR-LWE-2016-00036). Per DOE contractors, the pump was typically capable of lowering the liquid level to approximately 5 cm (2 in) or less if ventilation were running. To date, DOE contractors have not added or applied dry cementitious materials to assimilate or absorb pools of excess water in any grouted tank (ADAMS Accession No. ML22131A348, response to Q13), although a Tank 12H work order describes this option (WO 01337683-33).

Dehumidification with heating was also employed in the tank primary to evaporate water (ADAMS Accession No. ML16167A237). During the May 17, 2016, teleconference, DOE indicated that it is working with SCDHEC to enable original, operational ventilation systems to remain in place during future grouting operations (ADAMS Accession No. ML16167A237) to better manage water ingress, and provided a status update during the April 28, 2022, teleconference (ADAMS Accession No. ML22131A343). Although complete isolation prior to grouting operations was originally required by the State of South Carolina, the Consolidated

General Closure Plan (SRR-CWDA-2017-00015) allows partial isolation and isolation of utilities during post-stabilization. Ventilation, electrical, air, and water utilities may be left operational during grouting of the tank to aid in As Low As Reasonably Achievable (ALARA) practices (SRR-CWDA-2017-00015). This capability will apply to closure of Tank 15H (ADAMS Accession No. ML22131A348, response to Q14).

Annulus and Ventilation Duct Grouting

During the February 2–3, 2016, onsite observation visit, DOE stated that Tank 12H annulus cameras were in the East and West Risers and that one might also be placed in the South Riser, but that none could be placed in the North Riser (ADAMS Accession No. ML16111B174). DOE has since clarified that video cameras in the Tank 12H annulus were only in the East and West Risers (SRR-CWDA-2020-00052, Attachment 2). For improved visibility of annulus grouting operations, the NRC staff previously indicated that DOE should consider placing video cameras in *all* tank annuli risers, if available, or else consider repositioning cameras during grouting operations if they cannot be placed in all risers simultaneously (ADAMS Accession No. ML14342A784).

During the February 2–3, 2016, onsite observation visit, DOE noted that placement of Lifts 2 and 3 in the Tank 12H annulus and horizontal ventilation duct was delayed due to accumulated groundwater that had leaked into the annulus (Figure 4). While DOE pumped out most of the standing water and waited for the rest to evaporate during the week of this onsite observation visit, Tank 12H grouting proceeded directly from placement of Lift 1 to 4 in the primary (ADAMS Accession No. ML16111B174).

Annulus grouting commenced on 8 February 2016, and was completed on 1 March 2016 (SRR-CWDA-2016-00068; ADAMS Accession No. ML20280A286) except for the vertical ventilation duct, which was grouted later. Structural-support–related grouting procedures used when grouting the annuli of Tanks 5F, 6F, and 12H have involved pre-grouting (Lift 2) from the steel pan up to the base of the smallest horizontal duct, 15 to 30 cm (6 to 12 in) above the pan (e.g., SRR-LWE-2014-00147). During the May 17, 2016, teleconference with NRC, DOE indicated that if a horizontal ductwork is substantially intact, they will always fill horizontal annulus ventilation ducts from inside, via the vertical inlet and exhaust ducts as grout entry points (ADAMS Accession No. ML16167A237). Grout poured into the vertical ductwork inlet was observed by a camera in the East Riser to flow out of two ventilation registers or air supply slots [i.e., 15 cm × 36 cm (6 in × 14 in) openings in the top of the horizontal duct into the annulus (SRR-CWDA-2016-00068). DOE interpreted that the grout observed flowing out of the registers indicated that this section of the ductwork was filled with grout (SRR-CWDA-2016-00068). DOE concluded that the entire horizontal ventilation duct was sufficiently filled with grout because, during a complete camera-based inspection conducted in 2012 (C-ESR-G-00003, Revision 13), the duct had no collapsed areas that could obstruct grout flow. A total of 16 rectangular ventilation registers (Figure 5) in the top of the horizontal ductwork provided openings, spaced 5 m (17 ft) apart, into or from which grout could flow during duct and annulus grouting (SRR-CWDA-2016-00068; SRR-CWDA-2020-00058).

Except for Tank 16H, other grouted tanks have had their vertical inlet and exhaust sections of their ventilation ducts filled nearly simultaneously with external placement of grout in the annuli to ensure the structural integrity of the ducts was maintained. DOE indicated that it returned to this cautious approach when grouting the annulus and ventilation duct of Tank 12H (ADAMS Accession No. ML16167A237), however, dates that DOE subsequently provided for grouting of the vertical ventilation ductwork occur *after* dates when the bulk annulus grouting occurred.

The Tank 12H closure module (SRR-CWDA-2014-00086) indicated that a more flowable grout might be used to grout future ventilation ducts, and DOE reiterated the potential use of a more flowable grout for ductwork during the February 2–3, 2016, onsite observation visit. A work order for grouting the tank interior indicated that Lifts 5, 7, and 9 would partially consist of cooling coil grout placed inside the annulus ventilation duct (WO 01337683-33), to address the issue of grout flowability within the ductwork.

Figure 5. Photograph of Rectangular Ventilation Register in the Annulus, as viewed from the West Riser. Date of Video: January 19, 2016.

DOE indicated that groundwater was observed flowing into the vertical ventilation inlet duct (SRR-CWDA-2020-00058) of the Tank 12H annulus through a crack in the clay ventilation duct wall on March 2, 2016 (SRR-CWDA-2016-00068; ADAMS Accession No. ML22131A348, response to Q15). DOE contractors speculated that groundwater was leaking into the clay pipe ductwork because its elevation is below the water table (SRR-CWDA-2016-00068).

Approximately 1,893 L (500 gal) of water was pumped out of a vertical leg of the ventilation duct between April 14 and 15, 2016, leaving an estimated 5-cm (2-in) water-level in the annulus when the final grout was placed on April 15, 2016 to fill the dehumidification ductwork inlet (SRR-LWE-2016-00036; SRR-CWDA-2016-00068; ADAMS Accession No. ML22131A348, response to Q15). The water level in Tank 12H was measured with a steel tape, i.e., workers dropped a weighted measuring tape into the water and read the water level from the tape with a camera (SRR-CWDA-2016-00068). DOE contractors estimated the rate of groundwater in-leakage was approximately 22.7 L/hr (6 gal/hr) (SRR-CWDA-2016-00068; ADAMS Accession No. ML22131A348, response to Q15). Two Super Sacks® (BAG Corp, Richardson, Texas) of flowable cooling coil grout (WSRC-STI-2008-00172) were placed into the Lift 5 vertical ductwork approximately 1.5 hrs after groundwater was pumped out (WO 01337683-33; SRR-LWE-2016-00036; SRR-CWDA-2016-00068; ADAMS Accession No. ML22131A348, response to Q17). It is NRC staff's understanding that this is the first tank for which cooling coil grout was placed into an annulus ventilation duct. The remainder of Lift 5 external to the ductwork was placed with reducing tank grout (ADAMS Accession No. ML22131A348, response to Q17). When water was discovered to be collecting on top of grout in the annulus ductwork, DOE combined Lifts 7 and 9 into a single lift to fill the remainder of the annulus outside of the duct and then, after removing water, finished internally grouting the duct. No cooling coil grout was used in Lifts 2, 3, 7 and 9 (SRR-LWE-2016-00036; ADAMS Accession No. ML22131A348, response to Q17). Lift 5 holds approximately one-third of the annulus grout volume, located above the horizontal ductwork. DOE stated that there was no distinct concern that led to use of the more flowable cooling coil grout inside the Lift 5 vertical ductwork (ADAMS Accession No. ML22131A348, response to Q17). DOE maintains that the final physical and chemical properties of the hydrated cooling coil grout placed into the Tank 12H vertical dehumidification ductwork are consistent with HTF PA assumptions for waste tank stability and near-field hydrologic transport, or what they referred to as tank flow modeling (SRR-CWDA-2016-00068). DOE stated that the "small amount of water in the dehumidification duct would not create grout property conditions different from those assumed" in the HTF PA (SRR-CWDA-2016-00068).

The continuity of grout placement when filling contaminated ducts is particularly important. Uninterrupted flow of grout is essential to ensure that permanent porosity does not develop inside ductwork. DOE should try to place and position cameras in such a manner as to maximize visualization of grout entry and exit from ventilation duct registers.

Improved visualization will increase the evidentiary support for ventilation duct voids having been filled and will enhance DOE's ability to develop lessons learned related to grout placement strategies that will increase the likelihood that ducts are fully grouted and do not contain risk-significant void space (ADAMS Accession No. ML16231A444).

DOE contractors pre-estimated that 446 cubic meters (583 cubic yards) of grout would be required to fill the Tank 12H annulus (SRR-LWE-2016-00036), but approximately 469 cubic meters (613 cubic yards) were placed into the annulus (SRR-CWDA-2016-00068) based on the number of cement mixer trucks that discharged grout and assuming a nominal volume of 6.1 cubic meters (8 cubic yards) of grout per truck. This final calculated volume of grout placed into the annulus was as much as 4.9 percent greater than the pre-estimated volume needed, suggesting that no significant voids remained in the annulus upon completion. NRC staff will continue to evaluate technical issues associated with grouting the annuli and ventilation ductwork of waste tanks during future monitoring activities.

Equipment Grouting

Tank primary and annulus baseline inspections were performed with one video camera moved from riser to riser to verify and document the presence of expected in-tank equipment prior to commencement of grouting operations (SRR-LWE-2014-00162). Equipment to be grouted in place or entombed in grout within Tank 12H included an abandoned transfer jet in Riser 6, a submersible transfer pump in Riser 7, thermowells in Risers 4 and 7, an abandoned dewatering pump in the Center Riser, a robotic sampling crawler near Riser 4 and the west wall of the valve house, and an annulus jet in the North Riser (SRR-LWE-2014-00162). SRR-LWE-2015-00032 provides the grout formulation (T1A-62.5FA) used to grout voids within in-tank equipment in Tank 12H. Voids were grouted with a pre-blended mix of cable grout, slag, fly ash and water (WO 01337683-51) that had been designed and tested to flow into and fill small spaces (SRNL-STI-2011-00592). The formulation called for Grade 100 slag cement, but DOE used Grade 120 slag to grout Tank 12H equipment. DOE indicated there are no regulatory requirements for the properties of equipment grout, so there are no quality control test requirements associated with its production (SRR-LWE-2015-00032). Equipment grout was mixed by SRR Construction and work was controlled via work order (SRR-LWE-2015-00032; WO 01337683-51).

During the February 2–3, 2016, onsite observation visit, DOE staff described equipment grouting operations (ADAMS Accession No. ML16111B174; see also SRR-CWDA-2015-00095) that would occur later, on April 7, 2016, long after the primary had been filled with grout. In-tank equipment resting on the floor of the primary or annulus were not filled with equipment grout (SRR-LWE-2016-00036), a possible exception being a thermowell housing on the floor of the primary below Riser 4, which was said to have been filled with 5.7 L (1.5 gal) of equipment grout (Table 3.2-1 of SRR-CWDA-2016-00068 contradicts Table 3 of SRR-LWE-2016-00036 in this regard). Equipment grout is prepared onsite in small batches. SRR personnel measure the dry ingredients by weight, pre-mix them, and then combine the premix with water per the formulation. The mixture hydrates using a low-shear mixer, and then a high-shear mixer is engaged to finish mixing and thin the equipment grout, after which there is a short timespan before it sets up. Equipment grout is metered using hand-poured buckets with known volume as it is slowly and deliberately placed into small openings in each piece of equipment using gravity-driven flow through a hose and funnel (SRR-LWE-2016-00036). Prior to filling with grout, equipment is vented by either drilling a vent at a high point or by removing components to open a vent in the equipment (SRR-CWDA-2016-00068; see also SRR-LWE-2014-00147). High point vents collect overflow and indicate that equipment filling is complete (SRR-LWE-2014-00013). The volume of grout accepted by each piece of equipment is recorded (SRR-CWDA-2016-00068), based on the total volume of buckets poured (SRR-LWE-2016-00036).

Estimated fill volumes for in-tank equipment were based on assumptions about internal void space and potential grout flow paths (SRR-CWDA-2016-00068). These estimates were later compared to actual grout volumes placed into the equipment. Equipment grout was delivered from buckets of a known volume (SRR-CWDA-2016-00068). The actual grout volumes used to fill in-tank equipment were based on bucket volume and the number of buckets poured. DOE contractors made a concerted effort to slowly, carefully pour the highly flowable grout into the in-tank equipment (see SRR-CWDA-2014-00086 for equipment list) to ensure filling of void space. As needed, DOE contractors attempted to fill challenging pieces of equipment multiple times, first allowing an initial (and then subsequent) pours of grout to flow in and settle before continuing the filling process (SRR-LWE-2016-00036). Grout poured to fill the Submersible Transfer Pump in Riser 7, thermowells in Risers 4 and 7, and other equipment in Tank 12H (see SRR-CWDA-2020-00052, Attachment 1) minimized the potential for formation of vertical fast flow paths in association with this equipment, which might otherwise have expedited delivery of water to residual material on the waste tank floor (SRR-LWE-2014-00147). Equipment grouting continued until the Tank 12H equipment was unable to receive additional grout. Grout delivery flow rate, settling time, and equipment venting are examples of parameters and techniques identified during mock-up testing that were controlled during grouting to minimize residual void space (SRR-CWDA-2016-00068). Exceptions (SRR-LWE-2016-00036) to the Tank 12H in-tank equipment grout plans (SRR-CWDA-2014-00086) that occurred are described next.

- In November 2015, a wall crawler with an ultrasonic wall thickness testing device was installed in the annulus East Riser; SRR-CWDA-2014-00086 did not list the crawler equipment because the report was published before the equipment was installed. After being used to conduct wall inspections, the crawler was abandoned in the annulus and entombed in grout (SRR-CWDA-2016-00068).

- The grout plan (SRR-CWDA-2014-00086) stated that the transfer jet in Riser 6 (SRR-CWDA-2020-00052, Attachment 1) would be grout-filled. DOE contractors found the abandoned transfer jet suspended in the riser below the top riser plate. Based on transfer jet location and misalignment with the riser plate opening, the jet could not be directly grouted. Instead, contractors gravity-fed an indeterminate amount of grout into the transfer jet when placing grout into the riser, and the transfer jet was entombed. DOE expects that this transfer jet is partially grouted but does not expect it to have a configuration and sufficient void space to appreciably impact grout performance (SRR-CWDA-2016-00068).
- SRR-CWDA-2014-00086 listed a high level liquid conductivity probe (HLLCP) in the North Annulus Riser and another in the South Annulus Riser (SRR-CWDA-2020-00052, Attachment 1). During grouting operations, however, DOE contractors discovered that both risers contained two HLLCPs, which were grouted (SRR-CWDA-2016-00068).
- DOE contractors found a spray lance in Riser 4 during grouting that was not listed in SRR-CWDA-2014-00086; it was grouted (SRR-CWDA-2016-00068).
- DOE contractors found a caisson lance installed in Riser 7 that was not listed in SRR-CWDA-2014-00086; it was grouted (SRR-CWDA-2016-00068).
- Two small dewatering pumps and hose sections that were not listed in SRR-CWDA-2014-00086 were entombed with grout (SRR-CWDA-2016-00068).

DOE indicated that its effort to fill the internal void space of in-tank equipment in Tank 12H was successful (SRR-LWE-2016-00036, SRR-CWDA-2012-00051), and provided a comparison between pre-estimated equipment grout fill volumes against actual fill volumes in Table 3.2-1 of the final configuration report. Two exceptions of note are worth mentioning:

- An additional 64 L (17 gal) was recorded as having been used to fill a submersible transfer pump (STP) in Riser 7 (SRR-CWDA-2020-00052, Attachment 1) because grout initially flowed out of the open end of the bottom of the pump; upon noticing the outflow, its grouting was halted until after grout was placed in the bottom of the STP caisson to seal the open end of the pump.
- A narrow annulus opening less than 1.27 cm (0.5 in) wide within a steam jet jacket inside the North Annulus Riser (SRR-CWDA-2020-00052, Attachment 1) was difficult to fill and received only 3.8 L (1.0 gal) of equipment grout, instead of a planned 32 L (8.5 gal).

The NRC staff will continue to monitor equipment grouting, equipment grout shrinkage, and testing of the recommended equipment grout fill formulation for future tanks.

<u>Cooling Coil Flushing and Grouting</u>

A recurring issue in the Tank 16H grouting operations lessons learned document (SRR-TCR-2015-00024), for which several recommendations were developed, was the cooling-coil grouting process. DOE indicates that grouting of cooling coils is the highest hazard grouting operation. One recommendation was to evaluate the impact on the PA of eliminating the cooling-coil grouting process, altogether. Until such time as it may be determined that the cooling-coil grouting process can be abandoned, however, a recommendation was made to develop a management control plan to conduct cooling-coil grouting dry runs. The lessons learned document also noted that use of decant totes during the intact cooling-coil grouting process resulted in high hazard potential and recommended their replacement with waste totes. Finally, it was recommended that a method be developed to flush cooling coils immediately prior to grouting to reduce associated hazards, use of resources, and setup time.

Tank 12H contains 36 chromate-water, 5-cm (2-in)-diameter, schedule 40 carbon steel, cooling coils (i.e., seamless pipes) in its primary (SRR-LWE-2014-00147; SRR-CWDA-2016-00068). Of these, 28 coils had failed, meaning they could not maintain pressure (SRR-LWE-2016-00036), and 8 coils were intact. The 0.6-m- (2-ft)-thick Lift 1 was first placed into the primary to provide structural support to the cooling coils (ADAMS Accession No. ML16167A237; SRR-CWDA-2016-00068) before they were filled. Lift 1, placed on January 19–20, 2016, was the minimum amount of grout needed to provide support to vertical coils, while maximizing the potential for guillotined or severed coils to vent during grouting (SRR-LWE-2014-00147; ML18247A080, Slide 21).

WSRC-STI-2008-00172 provides the cooling coil grout formulation (90 wt% Masterflow 816 and 10 wt% Grade 100 ground granulated blast furnace slag cement, plus water). Masterflow 816 is marketed by BASF Corporation as a cement-based, aggregate-free, fluid, non-shrink, non-bleeding, high-strength cable grout with extended working time. For Tank 12H, DOE used Grade 120 slag in place of Grade 100 slag to produce the cooling coil grout. There are no regulatory requirements for the physical properties of cooling coil grout, so no quality control or test requirements were associated with its production (SRR-LWE-2015-00032). The work orders that addressed cooling coil grouting are WO 01337683-50 (failed coils) and WO 01337683-31 (intact coils). WSRC-STI-2008-00172 indicates, however, that cooling coil grout is required to have a reductive capacity at least as great as tank grout, if not greater. Because the cooling coil grout formulation was selected before the formulation for tank grout, NRC staff verified that tank grout had a weight percent (wt%) of blast furnace slag cement (i.e., 6 wt%) that is less than that of cooling coil grout (7.5 wt%) (SRNL-STI-2011-00551; ADAMS Accession No. ML16231A444).

During the February 2–3, 2016, onsite observation visit, DOE staff described Tank 12H failed cooling coil grouting operations (SRR-CWDA-2015-00095 and ADAMS Accession No. ML16111B174). WSRC-STI-2008-00298 recommended that DOE employ a mixing system that could blend the quantity of material required to fill one or more cooling coils. The total volume of cooling coils ranges from 284 to 439 L (75 to 116 gal) (ADAMS Accession No. ML16111B174; SRR-CWDA-2015-00159). Therefore, 568-L (150-gal) batches of cooling coil grout (C-SPP-F-00057) were prepared and pumped into each failed cooling coil (WO 01337683-50). Dry ingredients were premixed at a vendor facility and delivered to the site in a Super Sack® (BAG Corp, Richardson, Texas) (ADAMS Accession No. ML15239A612). SRR Construction personnel then batched 284 L (75 gal) of water with the coil grout dry mix in one Super Sack and blended the materials for 6 min in a skid-mounted grout mixer (WO 01337683-31 and Attachment F; WO 01337683-50). Cooling coil grout was mixed in a hopper near the tank top, and SRR Construction used a small pump to deliver grout into cooling coils (SRR-CWDA-2016-00068). A hand pump was used to control pressure and flow to meter the grout into the cooling coils (ADAMS Accession No. ML15239A612). A totalizer at the flow meter provided the quantity of grout added to the coils in real time. Failed cooling coils were grouted on January 26, 27, and 29, 2016, from each end (inlet and outlet) per the grout strategy (SRR-LWE-2014-00147 and WO 01337683-50), and grouting was considered successful when grout was observed exiting the coil into the waste tank from the failure point (SRR-CWDA-2016-00068; ML18247A080, Slide 21).

During the May 17, 2016, teleconference, DOE indicated that, for worker protection, it would be best to flush intact coils once, immediately prior to grouting (ADAMS Accession No. ML16167A237). DOE abandoned triple rinsing of intact cooling coils during grouting of Tank 16H and double rinsing continued during grouting of Tank 12H (ADAMS Accession No. ML16167A237). WSRC-STI-2008-00298 called for filling intact cooling coils with water prior to grout placement to remove air, prevent air entrainment, and help ensure that a liquid-to-liquid interface is maintained during cooling coil grouting. Intact cooling coils were flushed once prior to grouting to remove chromate water, which was sent through hose connection to Tank 10H, Riser 3 (SRR-CWDA-2020-00052; WO 01337683-31-A; HTF-SKM-2015-00010). Intact cooling coils remained full of water after flushing (SRR-CWDA-2020-00052). After Lift 8 was complete and the primary had been filled with bulk grout (ML18247A080, Slide 21), flushwater remaining in the coils was flushed again on March 16, 2016, through hoses into stand-alone, 1,135-L (300-gal) gray-water collection totes by grout pumped into the coils (HTF-SKM-2015-00010); this process minimized air entrainment and helped maintain the water-to-grout interface inside the coils (ADAMS Accession Nos. ML16167A237 and ML22131A348, response to Q18). On March 17 and 21, 2016, the 8 intact cooling coils were grouted only from the coil inlet (SRR-LWE-2016-00036; ML22131A348, response to Q18). When a solid stream of grout was visually detected at the coil outlet, a minimum surplus of 38 L (10 gal) of grout was introduced to the coil to ensure complete filling (ADAMS Accession No. ML15239A612; SRR-CWDA-2015-00159; SRR-LWE-2016-00036; WO 01337683-31-F). The flushwater/grout volume accumulated in the gray-water collection totes was solidified and disposed of separately (ADAMS Accession No. ML15239A612; SRR-CWDA-2015-00159; SRR-LWE-2016-00036). DOE indicates that they plan to continue grouting cooling coils during future tank closure operations (ML22131A348, response to Q18).

WSRC-STI-2008-00298 demonstrated that internally grouted piping surrounded by an insulating material underwent significant temperature rise during hydration. During the March 26–27, 2014, onsite observation visit, NRC staff asked DOE how it controlled the temperature of cooling coil grout (ADAMS Accession No. ML14106A573). NRC staff also raised the issue of the potential for cooling coil grout to boil during hydration due to any significant insulation provided by external tank grout (ADAMS Accession No. ML14342A784). During the July 28–29, 2015, onsite observation visit, DOE contractors indicated that grouting of the Tank 16H primary was 94 percent complete when in-tank equipment and cooling coil grouting began (ADAMS Accession No. ML15239A612), which implied that the coiling coils were insulated by exterior grout when they were filled during the period from August 13–28, 2015 (SRR-CWDA-2015-00170, Attachment 1). Likewise, the Tank 12H primary had been filled with bulk grout when its eight intact cooling coils were grouted (ML18247A080, Slide 21). NRC recommends DOE monitor in-tank temperatures and continue to consider heat transfer requirements such that cooling coil grout does not exceed its boiling temperature after placement into a highly insulated system that is also producing its own heat of hydration (WSRC-STI-2008-00298). NRC staff will continue to monitor how DOE controls the temperature of freshly placed cooling coil grout under locally insulated conditions.

No exceptions occurred to DOE’s planned cooling coil grouting process, described in the Tank 12H closure module and grout strategy (SRR-CWDA-2014-00086, SRR-LWE-2014-00147, SRR-LWE-2016-00036). No information, however, was provided in the final configuration report regarding the estimated volumes of grout to be placed in the cooling coils versus the actual amounts that were placed in the cooling coils of Tank 12H. NRC staff will continue to monitor cooling coil grouting, cooling coil grout shrinkage, how DOE minimizes air entrainment and the potential for boiling, any future testing undertaken of the cooling coil grout formulation, and future coil grouting operations. NRC staff will also continue to monitor the steps that DOE takes to prevent in-process grouting delays that enable premature hardening of grout in coils before they are fully filled. DOE should consider making a backup grout slickline readily available that can be used if needed. NRC staff will continue to monitor future actions taken by DOE to prevent plugging of the cooling coil grout addition line.

Riser Grouting

Grouting of 9 risers in the primary tank (Risers 1–8 plus Center) and 4 risers in the annulus (E, W, N and S Risers) of Tank 12H was facilitated by removing equipment components from risers and disconnecting and lowering hoses and cables onto the Tank 12H grout of the filled primary (SRR-LWE-2014-00147; SRR-CWDA-2016-00068). The work order that addressed grout preparations for riser fill is WO 01337683-33.

It was pre-estimated that 18 to 21 cubic meters (23 to 28 cubic yards) of tank grout would be required to fill primary Risers 1–8 plus Center, including four spray chambers (WO 01337683-33; SRR-LWE-2016-00036; Table 3), but DOE clarified that these riser volumes were misestimated (ADAMS Accession No. ML22131A348, response to Q22), in part because bulk fill grout used to grout the primary also partially filled the primary risers before riser grouting formally began (SRR-CWDA-2016-00068). This implies that the actual grout volume recorded as having been used to fill the primary is *overestimated* because some of that grout partially filled some primary risers. Given this, only approximately 11 cubic meters (15 cubic yards) of tank grout were recorded as having been used to fill the primary risers and four spray chambers (SRR-LWE-2016-00036; Table 3). DOE likewise pre-estimated that 10 to 17 cubic meters (12.8 to 22 cubic yards) of tank grout would be required to fill four annulus risers (East, South, West, and North; WO 01337683-33; SRR-LWE-2016-00036; Table 3), but only 8.4 cubic meters (11 cubic yards) of tank grout were recorded as having been used to fill the four annulus risers (SRR-LWE-2016-00036; Table 3). Visual inspections conducted by DOE contractors indicated the risers and spray chambers were filled with grout (SRR-CWDA-2016-00068). DOE previously stated that riser volume estimates should not be considered highly accurate because these estimates are based on the total time it takes to completely discharge one truckload of tank grout and the time it takes to fill a riser (ADAMS Accession No. ML14106A573).

Groundwater in-leakage from a source near the bottom of Riser 8 was informally estimated by DOE contractors to be 18.9 L/hr (5 gal/hr). After the liquid had been pumped down to an approximately 5 cm (2 in) level, grout was placed into Riser 8 in less than 1.5 hrs (SRR-CWDA-2016-00068; SRR-LWE-2016-00036), suggesting that <28.5 L (<7.5 gal) of groundwater had been able to leak in during the interim. DOE considered the amount of liquid observed in Riser 8 to be inconsequential to grout integrity (SRR-CWDA-2016-00068). DOE maintains that the final physical and chemical properties of the hydrated tank grout are consistent with HTF PA assumptions for waste tank stability and hydrologic transport, or what they referred to as “tank flow modeling” (SRR-CWDA-2016-00068). DOE stated that the “small amount of water in the riser would not create grout property conditions different from those assumed” in the HTF PA (SRR-CWDA-2016-00068). DOE noted that no free liquid was observed in Riser 8 while it was being filled with grout (SRR-CWDA-2016-00068).

Final Configuration

The final configuration of Tank 12H and deviations from the closure module (SRR-CWDA-2014-00086), are described in SRR-CWDA-2016-00068, but uncertainties exist in the fill volumes reported. In the final configuration report, DOE indicated that the final calculated reducing grout volumes reported were based on the total number of grout batches (i.e., truckloads) discharged into the tank and annulus, assuming 6.1 cubic meters (8 cubic yards) per load of tank grout (SRR-CWDA-2016-00068). The final calculated reducing grout volume placed into the Tank 12H primary was within 2.2 percent of the pre-estimate, and the volume placed into the annulus was as much as 4.9 percent greater than anticipated.

The volume of tank grout placed into the primary and annulus risers of Tank 12H was 42 percent less than anticipated, possibly because lower portions of risers had been filled earlier, during tank and annulus grouting operations. Because DOE does not account for the amount of each grout batch that is used for testing and discarded, the relatively small riser grout volume estimates are particularly uncertain. DOE previously stated that riser volume estimates should not be considered highly accurate because these estimates are based on the total time it takes to completely discharge one truckload of tank grout and the time it takes to fill a riser (ADAMS Accession No. ML14106A573).

The final configuration report compares the pre-estimated equipment void volume and the final calculated volume of buckets and the number of buckets used to deliver equipment grout (SRR-CWDA-2016-00068, Table 3.2-1). Neither the Tank 12H final configuration report (SRR-CWDA-2016-00068) nor the Tank 12 final configuration report inputs (SRR-LWE-2016-00036) discussed the pre-estimated void volume of cooling coils in Tank 12H or the final calculated volume of grout placed into its cooling coils.

ASTM C39 compressive strength testing indicated that the strength of emplaced tank grout exceeds the compressive strength assumed in the HTF PA (SRR-CWDA-2010-00128). The average 28-day compressive strength of tank grout placed into Tank 12H was 16,430 kPa (2,383 psi or 164 bars), well above the minimum acceptable value of 13,800 kPa (2,000 psi or 138 bars) described in the closure module (SRR-CWDA-2014-00086).

DOE should consider ways to improve grout volume pre-estimates and final calculated grout volumes placed for the tanks, annuli, equipment, cooling coils, and risers to help ensure void space is fully grouted and better understand the nature of any remaining void space. One option would be to create an overall tally of the void volume estimated for the primary, annulus, and risers, and compare this sum to the overall volume that was placed into the three areas of each tank. DOE could also provide information on volume and void volume uncertainty (or uncertainty in each of the data and measurement components that go into the void volume/percent calculation).

Quality Assurance

Quality control of Tank 12H grout production and delivery were implemented in accordance with the grout procurement specification (C-SPP-F-00055, Revision 4, Attachment 5.5). DOE's quality control program included documentation of grout component compliance with specified standards, compressive strength testing of hydrated grout test cylinders, and surveillance and audits of grout production and delivery activities. DOE's closure assurance plan for Tank 12H, as described in SRR-LWE-2015-00032, is clear and should ensure that Tank 12H was closed according to plan, while meeting all regulatory process and documentation requirements. This document, reviewed previously, indicated that the tank grout formulation to be placed into Tank 12H could exercise the option to use Grade 120 slag cement, whereas Grade 100 had been used during prior tank grouting operations. The NRC staff will continue to evaluate whether the DOE closure assurance plan is being implemented effectively during future onsite observation visits and technical reviews.

Teleconference or Meeting

A WebEx teleconference was held between NRC and DOE on December 9, 2020, the purpose of which was to share information on similar research performed by CNWRA and SREL on conditioning of infiltrating groundwater by reducing tank grout (ADAMS Accession No.

ML21026A012). Greg Flach discussed SREL research during this teleconference that showed the E_h endpoints (both minimum and maximum E_h values) assumed in PA modeling were unable to be achieved during lab work (SREL Doc. R-21-0001; SRR-CWDA-2020-00061; SRR-CWDA-2020-00085). Greg Flach indicated that updated geochemical modeling would be pursued to better understand radionuclide solubility. NRC indicated that it would be important to update geochemical modeling for solubility, as well as for E_h evolution, because even if the E_h were known, the solubility-limiting phases in the pH/E_h diagrams from PA modeling do not appear correct. For example, solubility of key radionuclides such as Pu, Tc, and U were orders of magnitude higher than observed for any assumed chemical state. DOE agreed it planned to update the geochemical modeling, including an update of mineralogy, and potentially using a new thermodynamic database.

During a January 11, 2022, meeting between NRC and DOE to discuss the status of F-Area and H-Area tank farm (FTF and HTF) facility activities, NRC and DOE agreed to have a follow-up meeting to discuss Revision 0 of this report (i.e., ML20296A550). This follow-up teleconference occurred on April 28, 2022. The April 28, 2022, meeting summary is found at ADAMS accession no. ML22131A343 and Appendix B of this report documents the status of NRC questions to DOE that were presented in Appendix B, Revision 0 of this report.

Follow-Up Action Items

NRC staff will continue to monitor DOE's bulk fill, equipment, and cooling coil grout formulations under Monitoring Factors 3.2 "Groundwater Conditioning via Reducing Grout," 3.3, "Shrinkage and Cracking," and 3.4, "Grout Performance" listed in NRC staff's Tank Farm Monitoring Plan (ADAMS Accession No. ML15238A761) while focusing on the technical issues listed in this technical review report and on any new technical issues that arise. Twenty-three (23) follow-up action items (FUAI) identified in Appendix B of Revision 0 of this report were addressed by DOE.

Open Issues

No open issues resulted from this technical review. However, insufficient information is provided to address the likelihood for preferential flow pathways that enable bypass flow to form through grout monoliths due to shrinkage, cracking, and void space. NRC staff will continue to follow-up on this technical issue under 3.2 "Groundwater Conditioning via Reducing Grout," and Monitoring Factor 3.3, "Shrinkage and Cracking" (See ADAMS Accession No. ML15238A761).

Conclusions

Due to the similarities in the grout formulation and approach to grouting Type I Tanks 5F, 6F, and 12H, Type II Tank 16H, and Type IV Tanks 18F and 19F, many of the conclusions resulting from the NRC staff's previous reviews of documentation related to Tanks 5F, 6F, 18F, 19F, and 16H remain relevant to the review of Tank 12H grouting operations. Relevant major and minor conclusions from the Tanks 5F, 6F, 18F, 19F and 16H reviews are repeated below along with new conclusions from the Tank 12H review.

Major Conclusions for Tanks 18F and 19F:

- The NRC staff concludes that performance requirements for grout formulations recommended and tested for Tanks 18F and 19F closure are generally consistent with bulk, initial chemical and hydraulic properties assumed in DOE's FTF Performance

Assessment (SRS-REG-2007-00002, Rev. 1). The NRC staff also concludes, however, that DOE has not provided sufficient information and testing to support its exclusion of shrinkage gaps, cracks, and other preferential flow fast pathways through the tank grout monolith from its reference case. DOE's reference case assumes that grout degrades slowly with gradual increase in matrix saturated hydraulic conductivity. Primarily, the NRC staff expects DOE to provide additional information related to the extent and performance impact of shrinkage and other preferential fast flow pathways to have reasonable assurance that the performance objectives specified in Subpart C of Part 61 of Title 10 of the Code of Federal Regulations (10 CFR Part 61, Subpart C) will be met. NRC staff consider tank grout shrinkage to be its highest priority technical issue related to engineered barrier performance.

- Further, during the review of tank grouting video, NRC staff observed potential segregation of tank grout from excess water that could enhance the extent of shrinkage along the periphery of the Type IV tanks (i.e., along the tank walls). The NRC staff will continue to evaluate the potential for shrinkage- and cracking-induced preferential flow through the tank grout under Monitoring Factor 3.3, "Shrinkage and Cracking" (See ADAMS Accession No. ML15238A761). NRC also continues to monitor the potential for segregation of emplaced grout and its impacts on flow through the grout monolith and waste release under Monitoring Factor 3.4, "Grout Performance."

Minor Conclusions for Tanks 18F and 19F:

The NRC staff will also continue to monitor void volumes in the emplaced grout to the extent that information is available (Monitoring Factor 3.4, "Grout Performance"), the importance of alkali-silica reactivity on cementitious material degradation (Monitoring Factor 3.3, "Shrinkage and Cracking") and the impact of up to 5 wt% limestone in Portland cement on pH buffering of water contacting the emplaced grout (Monitoring Factor 3.4, "Grout Performance"). NRC staff also expects DOE to provide additional information about the potential for thermal cracking of the grout monolith for Tanks 18F and 19F.

Major Conclusions for Tanks 5F and 6F:

Major and minor conclusions[8] from the Technical Review Report for Tanks 18F and 19F grouting were repeated in the Tanks 5F and 6F Technical Review Report. Additional conclusions (or additional detail regarding a previous conclusion) were also listed as below:

Additional Conclusions for Tanks 5F and 6F:

- NRC staff observed grout with higher flowability in the Tanks 5F and 6F grouting operation videos compared to that placed into Tanks 18F and 19F due to the higher slump specified for use in tanks with cooling coils.
- NRC staff observed, via video, potential instances of bleed-water segregation (e.g., mottling of grout that may be due to incomplete mixing or segregation, bright watery sheen at the leading edge of the fresh grout flow lobe, strong color differentials). While NRC staff acknowledges the potential for these observations to be due to the Slick Willie pump priming agent, chromated water, or due to shadows caused by lighting

[8] Major conclusions are considered high to medium priority, while minor conclusions are low priority. The highest priority item continues to be tank grout shrinkage and the potential for preferential fast flow pathways bypassing reducing tank grout interactions within the engineered system.

angles, making that determination is subjective and the priming agent or water may have a potential impact on hydraulic properties and grout quality.

- DOE should minimize or eliminate excess water introduction to waste tanks and provide evidence that introduction of excess water (e.g., in the form of Slick Willie) into Tanks 5F and 6F (and 18F and 19F) did not reduce the integrity of the tank grout to less than what is assumed in the FTF PA (SRS-REG-2007-00002, Revision 1).
- DOE should take reasonable measures to prevent future placement of out-of-specification grout because inhomogeneity in the grout will affect flow in the monolith due to higher permeability zones fostering higher flow rates than surrounding zones.
- DOE should consider giving higher priority to development and testing of a shrinkage compensating tank grout formulation.
- Given that only approximately 50 percent of the tank annuli were visible in videos documenting annulus grouting, DOE should consider placing video cameras in all riser locations within tank annuli during grouting operations or else occasionally reposition video cameras into different available risers to improve visibility.
- Two of the failed cooling coils were only partially filled because DOE had not adequately cleaned the grout slickline prior to the fill, which allowed grout residue to plug the slickline. NRC staff notes that the lessons learned report (SRR-CWDA-2014-00015) provides several suggestions to prevent plugging of the cooling coil grout slickline (e.g., increasing flush frequency, increasing flush water velocity, installing screens to prevent solids from plugging the line, increasing the pig diameter, and pre-charging the line with water). NRC staff will continue to monitor DOE’s actions to prevent plugging of the cooling coil grout slickline.

<u>Major Conclusions for Tank 16H</u>:

- DOE should take reasonable measures to ensure enough cement trucks are in rotation to optimize grout distribution throughout the tank and minimize mounding.
- DOE should take measures to continuously fill cooling coils with grout to ensure complete filling and to avoid creating grout blockages within intact coils that could have otherwise been fully filled (SRR-CWDA-2015-00159). Complete filling of cooling coils is needed to eliminate in-tank void space and preferential flow paths. DOE should continue to document related lessons learned and implement a path forward that will mitigate future occurrences of grout blockages.
- DOE should consider heat transfer requirements such that cooling coil grout does not exceed its boiling temperature after placement into cooling coils insulated by tank grout, which is also producing its own heat of hydration (WSRC-STI-2008-00298).
- DOE should seek to understand why reducing tank grout placed into Tank 16H mounded excessively beneath tremies in the discharge zone, to minimize the likelihood of this phenomenon’s recurrence during future grouting of other tanks.
- NRC recommends that DOE monitor in-tank temperatures during grouting operations, especially given the (i) mounding phenomenon that took place inside Tank 16H during its summer grouting season, (ii) potential for thermal cracking of large, hydrating grout monoliths, and (iii) potential for cooling coil grout to boil when placed subsequent to placement of the entire volume of reducing tank grout in the primary, thereby surrounding and thermally insulating coils from every direction.
- NRC staff observed via Tank 16H grouting video instances of bleed-water segregation. Non-uniformly distributed excess water in the tank and annulus may have a potential impact on hydraulic properties and grout quality, and enhance shrinkage along the tank

wall, resulting in unintended inhomogeneous material properties that would affect water percolation patterns through the monolith. DOE should remove or absorb excess ponded water from the tank before, during, and near the end of grouting operations, whenever aqueous ponds are present, to ensure adequate quality grout is placed into tanks and annuli. Alternatively, DOE could provide additional information to support a determination that the quantities of water present in the tanks during grouting do not adversely impact grout performance.

Major Conclusions for Tank 12H:

- Regarding the change in slag from Grade 100 to Grade 120 during Tank 12H grouting, DOE should address the performance impact of using two different slag cements in Tank 12H reducing tank grout: Holcim Grade 100 grout [163 cubic meters (213 cubic yards)] was placed in the bottom of the first lift in the primary and Lehigh Grade 120 grout [2,840 cubic meters (3,714 cubic yards)] was placed above. DOE should evaluate differences in chemical reactivity, saturated hydraulic conductivity, and compressive strength between the Grade 100 and Grade 120 slag tank grouts and any resulting performance impact. NRC staff will continue to monitor the impact of slag grade on chemical reactivity, saturated hydraulic conductivity, and compressive strength of reducing tank grout.
- DOE has not provided sufficient information about the potential impact of excess water present in submerged, grouted tanks, such as Tank 12H, on the quality of grout placed into the tank, and therefore on anticipated performance of tank grout in a submerged or partially submerged tank. DOE should undertake analyses to better understand the impact on grout performance and grout quality of the significant amount of liquid present in submerged tanks that interacts heterogeneously with tank grout, both during early days post-placement and longer term. DOE should provide information about the potential impact on grout performance of standing water in Tank 12H during grouting and of heterogeneous water-to-cement ratios in tank grout when grouting submerged tanks. The NRC staff will monitor potential impacts of high levels of saturation in partially submerged to submerged tanks. The NRC staff will monitor how DOE contractors grouted around pools of water that remained on the floor of Tank 12H immediately before grouting commenced, and any potential impacts that may have been associated with grouting around pools of standing water. The NRC staff will continue to monitor the potential for grout bleed-water segregation and potential impacts on future water flow through the grout monolith and waste release.

On a related topic, NRC staff will continue to monitor the impact of submerged groundwater conditions on waste release from H-Tank Farm tanks, such as Tank 12H, as discussed in more detail in ML19298A092. The key radionuclide contributing to dose in DOE’s PA for Tank 12H is I-129. Therefore, NRC staff will monitor the impact of groundwater chemistry on I-129 attenuation and dose, including the impact of aquifer chemistry on I-129 waste release from submerged tanks, such as Tank 12H. Additionally, due to significant variability in Tank 12H and Tank 18F waste release results and difficulty extrapolating results to other tanks, NRC staff will continue to monitor the extent of groundwater conditioning via reducing tank grout, as well as the impact of waste geochemistry on key radionuclide release from other tanks at FTF and HTF.

In this report, there is no significant change to the NRC staff overall conclusions from the F- and H-Tank Farm TERs regarding compliance of DOE disposal actions with the 10 CFR Part 61 performance objectives. Likewise, there is no significant change to the status of Monitoring

Factors 3.2 “Groundwater Conditioning via Reducing Grout,” 3.3, “Shrinkage and Cracking,” and 3.4, “Grout Performance” listed in the NRC staff’s Monitoring Plan for the tank farm facilities (ADAMS Accession No. ML15238A761).

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WO 01337683-31-F. “Attachment F – Coil Grout Spreadsheet.” [ADAMS Accession No. ML20279A794]

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WO 01337683-33-B. “Attachment B – Tank 12 Cleaning/Pigging of Slickline.” [ADAMS Accession No. ML20279A797]

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Appendix A

Summaries of General Grout Documents:

C-SPP-Z-00012. Patel, R. "Vault 4 Clean Cap Grout (Procurement Specification)." Revision 1. Aiken, South Carolina: Savannah River Remediation, LLC. March 20, 2014. [ADAMS Accession No. ML16117A359]

This document is a detailed listing of the procurement specifications for furnishing and delivery of three alternative mix designs for Saltstone Disposal Facility Vault 4 clean cap grout, including trial batching to demonstrate the grouts will meet specification requirements. The production mixes and minimum slump flow requirements are described in Attachment 5.5. Clean cap grout, like saltstone, is comprised of a 45/45/10 wt% mixture of Thermally Beneficiated Class F fly ash, Grade 100 ground granulated blast furnace slag cement, and Type II ordinary Portland cement mixed with an aqueous solution. Mix nos. 1 and 2 use water as the mixing solution with water-to-cementitious material (w:c) ratios of 0.50 and 0.45, whereas Mix no. 3 uses a 6 wt% caustic sodium hydroxide (NaOH) aqueous solution with NaOH:c ratio of 0.53, instead, to reduce the tendency for fine-grained slag in the mix to increase bleed-water production (cf. VSL-14R3330-1). American Concrete Institute (ACI) and ASTM International (formerly the American Society of Testing and Materials) standards and specifications are generally specified. All mix designs called for ASTM C1611 slump flow to be in the range of 26–38 in (66–97 cm). The batch plant capacity is specified as (i) sustained average capacity of 400 yd^3/day [306 m^3/day] through a 5-day workweek and (ii) sustained average capacity of 40 yd^3/hr [31 m^3/hr] for an 8-hr period. Procedures for addressing and dispositioning supplier deviations are presented.

C-ESR-G-00003. Waltz, Jr., R.S. "SRS High Level Waste Tank Crack and Leak Information." Revision 13. Aiken, South Carolina: Savannah River Site. 26 October 2015. [ADAMS Accession No. ML14079A609]

This report documents the location of known cracks and provides estimates of the quantity of leaked waste that remains on the floor of the annulus of the underground high-level waste storage tanks. The document is revised regularly as new cracks or other evidence are found. Revision 13 contains all known conditions as of 26 October 2015, including leak sites identified in Tank 15. This technical review report is the first to have reviewed the tabulation of data contained within C-ESR-G-00003. A portion of the Revision 13 summary table is captured below for SRS tank closure activities that NRC has monitoring responsibilities for under the 2005 NDAA. Based on this table, review of Revision 11 would provide a more complete understanding of the available information about cracks, leak sites, and waste in the annuli in SRS's underground HLW storage tanks.

Tank	Tank Type	Known Leak Sites	Date of Discovery	Waste on Annulus Floor?	Amount of Waste (est)	Location *	Elevation from Tank Base	Tank Wall Inspected	Acceptable Fitness for Service
5	I	44	See Rev 11						
6	I	11	See Rev 11						
12	I	15	1984 May 1974 Apr 2004 Oct 2005 Oct 2005	Yes	Waste total for leak sites 1–4 on wall & floor: 2 gal	1 North 2 North 3 North 4 North 5 South 6 NE	93 in 105 in 95 in 70 in 129 in 85 in	25% (typical)	Yes - Tank flaws evaluated

			2008– 2012		1 cup 3.4 gal				against calcs: T-CLC-G- 00159 & T-CLC-H- 00639 and are acceptable
			Jul 2012 Jul 2012 Jul 2012 Jul 2012 Jul 2012 Jul 2012 Jul 2012 Jul 2012 Jul 2012		nodule ¼ gal 1 cup 1 cup 1 cup nodule nodule ½ cup ½ cup	7 SW 8 SW 9 NW 10 NW 11 NW 12 NW 13 NW 14 SE 15 SE	129 in 129 in 129 in 230 in 230 in 129 in 129 in 129 in 129 in	100% - inspected by magnetic crawler device in 2001	
15	II	24	Apr 1972 Apr 1972 1973 1973 1973 1973 1973 1973 1973 1973 1973 1973 1973 1997 1998 1997 2000 2000 2002 2005 2015 2015 2015 2015	Yes	nodules on tank wall with trails to annulus floor and small amount of waste on annulus floor waste on annulus floor observed during re-wetting activities in July 2015 was ~1-2 in deep UT	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	34 in 34 in 150 in 88 in 30 in 96 in 30 in 74 in 30 in 30 in 150 in 34 in 150 in 150 in 150 in 200 in 30 in 30 in 129 in 31 in 73 in 100 in 92 in 126 in	96%	Yes - Tank flaws evaluated against calcs: T-CLC-G- 00159 & T-CLC-H- 00639 and are acceptable
16	II	~300– 350	No Data						
18	No Data								
19	IV	4	See Rev 11						Not Applicable
*circumferential feet from South riser, clockwise Note: leak sites detailed in this table were documented by the presence of salt nodules or stains and marks. Additional leak sites may exist in uninspected areas. One crack detected in 2002 in Tank 15 was located using UT techniques. Note: 1 in = 2.54 cm									

SDDR No. 13182. "Supplier Deviation Disposition Request No. 13182 (Slag Cement not Meeting ASTM C989, Grade 100)." Aiken, South Carolina: Savannah River Site. June 2015. [ADAMS Accession No. ML16119A339]

SDDR No. 13182, initiated in March 2015, proposed a deviation to Specification C-SPP-F-00055 to allow use of Grade 120 slag cement in lieu of Grade 100 (i.e., the "proposed action"). Because the deviation or proposed action would alter the tank grout formulation, the UWMQ Determination was initiated and an UWMQ Evaluation (UWMQE) was performed. UWMQE No. SRR-CWDA-2015-00088, "Use of Grade 120 Slag in Tank Closure Grout (USQ-HTF-2015-00300)" was approved, and the deviation was determined acceptable because its implementation would have no adverse impact on the facility or its systems, nor would it compromise PA conclusions. USQ-HTF-2015-00300 was previously reviewed in the Tank 16H TRR (ADAMS Accession No. ML16231A444). UWMQE No. SRR-CWDA-2015-00088 (ADAMS Accession No. ML16057A471) was also previously reviewed in the Tank 16H TRR.

SREL Doc. R-21-0001. Seaman et al. "Aqueous and Solid Phase Characterization of Potential Tank Fill Materials." Aiken, South Carolina: Savannah River Ecology Laboratory. August 20, 2020. [ADAMS Accession No. ML20303A339]

To address uncertainty in realistically achievable E_h ranges for tank grout, Savannah River Ecology Laboratory characterized the aqueous chemistry of three candidate tank fill grouts via a series of batch and column tests under a realistic range of atmospheric conditions: (i) LP#8-16, reducing tank grout referred to herein as Tank Closure Grout (TCG; 18% ordinary Portland cement; 30% ground granulated blast furnace slag; 52% fly ash); (ii) LP#8-16 except slag replaced by fly ash similar to CLSM mix ZB-FF-8-D, referred to herein as Tank Closure Grout with No Blast Furnace Slag (TCG-NBFS; 18% ordinary Portland cement and 82% fly ash), and (iii) EXE X-P-0-X (7.7% ordinary Portland cement and 92.3% fly ash), referred to herein as CLSM (not to be confused with CLSM mix ZB-FF-8-D, which is also known as Zero-Bleed CLSM). The TCG and TCG-NBFS mixes had tap-water-to-cementitious material ratios (w:cm) of 0.579, whereas the EXE-X-P-0-X mix had w:cm = 0.847. These three representative grout pastes (no aggregate) were allowed to hydrate and age for 90 days, then were size-reduced or granulated for use in batch tests or were size-reduced and mixed with clean quartz Ottawa sand consistent with the amount of sand called for in the grout formulas for use in column tests.
In batch experiments, the grout particulate matter was equilibrated with a pore-water simulant for 150+ days; pH and oxidation–reduction potential (E_h) were monitored weekly and small aliquots of leachate were sampled weekly and analyzed for major elements by ICP-MS.
In column experiments, the particulate grout plus sand were leached under saturated conditions with pore-water simulant either oxidized or else N_2-purged. Sand mixed with the particulate grout was deemed necessary for the column tests to maintain constant flow through the column while reproducing the formulated proportions of cementitious materials vs. sand in monolithic grout recipes.

Original dry feed cementitious materials, the three unleached candidate reference tank grouts, and leached grout samples also underwent solid-phase characterization by X-ray fluorescence (XRF) spectroscopy (as borate fused bead samples) and X-ray diffraction (XRD) spectroscopy. Inert quartz, mullite, hematite and magnetite crystalline phases in semi-amorphous fly ash were detected in both unleached and leached samples. Unleached samples contained strätlingite, calcite, ettringite, and varied alumina, ferric oxide, monosulfate (AFm). Leached samples did not contain ettringite, and AFm either disappeared or else decreased. Strätlingite persisted in most of the leached samples but was barely detected in any grout samples exposed to a reducing environment and was also barely detected in reducing tank grout samples subjected to any environment. Calcite persisted in all samples and especially samples subjected to an oxygenated atmosphere due to carbonation in the CO2 containing oxic environment. Hydrotalcite and possibly kuzelite or monosulfoaluminate were only observed in reducing tank grout samples; both minerals persisted in all leached reducing tank grout samples regardless of atmosphere. Hydrotalcite was expected to be present because of the magnesia (MgO) content of the slag cement (approximately 6wt% measured via XRF). Monosulfoaluminate is produced via reaction between tricalcium aluminate (a primary cement phase) and ettringite (a cement hydration product).

SRR-CWDA-2012-00051. Layton, M. "Critical Assumptions in the Tank Farm Operational Closure Documentation Regarding Waste Tank Internal Configurations." Revision 2. Aiken, South Carolina: Savannah River Site. 11 January 2016. [ADAMS Accession No. ML13078A206]

This report documented DOE's evaluation of the expected impacts of remnant artifacts (e.g., transfer jets, thermowells, level instrumentation, submersible mixers and pumps, cables, and temporary transfer hoses) left within waste tanks at the time of operational closure and clarifies the difference between negligible impacts from these artifacts and what should be considered significant changes to waste tank closure configurations. DOE considers remnant artifacts within waste tanks that are smaller than (i) cooling coils or (ii) large pieces of equipment to have generally negligible impact with respect to post-closure performance of the waste tank fill grout. Table 3.2-1 presents DOE's preliminary recommendations and general plan for final disposition (i.e., internally grouting, externally encapsulating, or neglecting to further consider) remnant artifacts and materials within waste tanks at the time of their closure. Artifacts and materials listed in the table were identified based on information provided in SRR-CWDA-2010-00003, SRR-LWE-2010-00175, SRR-CWDA-2011-00054, and SRR-LWE-2014-00147. Nevertheless, the final configuration report for each tank is the ultimate record of how such artifacts and materials were handled during grouting operations.

This report also summarizes the total volume of grout displaced by cooling coils in all SRS waste tank types (Table 4.2-3, repeated here):

Displaced Grout Volume Estimates for Cooling Coils in Select Waste Tank Types

Tank Type	Displaced Volume Estimate (gal)	Reference
Type I	5,243	C-CLC-G-00364
Type II	6,762	C-CLC-G-00364
Type III	2,060	M-CLC-H-02820
Type IIIA	3,708	M-CLC-H-02820
Type IV	NA/no coils	

Note: 1 gal = 3.8 L

DOE estimated that for Type IV waste tanks, in-tank equipment and remnant artifacts would have to displace more than 151,400 L (40,000 gal) of bulk grout to hasten the transition from reducing to oxidizing conditions to occur within the 10,000-yr performance period; all other waste tank types have later grout transition times. Based on these calculations, DOE conservatively selected 75,700 L (20,000 gal) per waste tank as the maximum amount of tank/vault volume that should be occupied by equipment and remnant artifacts when grouting commences; however, the total volume of grout displaced by equipment and remnant artifacts in each waste tank is anticipated to be less than 75,700 L (20,000 gal) in each case.
DOE anticipated that due diligence would be exercised by staff to limit the volume of remnant artifacts and materials left inside each tank so that a minimum volume of grout is displaced, and the waste tank is filled with grout to the extent practical. The report concludes that any changes to reducing capacity anticipated from materials left behind within waste tanks, which take up negligible fractions of the overall tank and annulus volumes, are not expected to negatively impact results relative to performance objectives defined in the FTF and HTF PAs.
The displaced volume of grout taken up by equipment and remnant artifacts in both Tanks 12H and 16H was less than 37,900 L (10,000 gal).

The report summarized the conclusions of the Grout Drop Test Report (RPT-5539-EG-0016), recommending that grout should not be placed directly into standing water due to the potential for significant segregation to occur and for its compressive strength to not meet specifications. However, the report also indicated that the presence of standing water in a tank or annulus during grouting would not necessarily cause segregation to occur or unsatisfactory compressive strength to develop if grout placement is highly controlled (i.e., not placed into standing water). Equipment flushes, which add incidental amounts of water to tanks or annuli, are assumed by DOE to result in water volume overages of approximately 3 percent (SRR-CWDA-2014-00102). DOE expects that in-tank water (e.g., rain, flush and/or bleed water) is expected to mix with grout during pouring, and to have a negligible impact on the grout (Table 3.2-1).

The report indicates that an easier-to-mix-and-pump alternative to tank grout may be emplaced in waste tank risers because the PAs did not assume that riser fill would have the same chemical and physical properties as tank grout. Instead, the PAs assumed that the tank risers are filled with a cementitious material that is equivalent to tank roof concrete (i.e., saturated hydraulic conductivity of 3.4×10^{-8} cm/sec) to impede groundwater infiltration.

<u>SRR-CWDA-2017-00015. “Consolidated General Closure Plan for F-Area and H-Area Waste Tank Systems.” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. 127 pp. February 2017. [ADAMS Accession No. ML20279A784]</u>

This report pertains to and supports the future removal from service of FTF and HTF underground waste tanks and ancillary structures regulated under the F- and H-Area High-Level Radioactive Waste Tank Farms Construction Permit No. 17424-IW and the SRS Federal Facility Agreement (FFA) that controls subsequent remediation of FTF and HTF. This consolidated general closure plan is not applicable to previously grouted Tanks 5F, 6F, 12H, 16H, 17F, 18F, 19F and 20F. This consolidated general closure plan supersedes LWO-RIP-2009-00009 Revision 3 (F-Area) and SRR-CWDA-2011-00022 Revision 0 (H-Area) general closure plans. The purpose of the plan is to describe the general protocol by which DOE intends to remove from service tanks at FTF and HTF that remain to be closed. The plan describes DOE’s method of stabilizing waste tank systems and residual contamination. The plan additionally describes the integration of the waste tank system closure activities with existing commitments to remove waste from the waste tank systems. Although complete isolation of waste tanks prior to grouting operations was originally required by the State of South Carolina, the Consolidated General Closure Plan allows partial isolation and isolation of utilities during post-stabilization. Ventilation, electrical, air, and water utilities may be left operational during grouting of the tank to aid in As Low As Reasonably Achievable (ALARA) practices. This capability will apply to closure of Tank 15H (ADAMS Accession No. ML22131A348, response to Q14).

<u>SRR-CWDA-2020-00052. Romanowski, L. “Follow-Up to Tanks 12H and 16H Grouting Operations Document Request in Support of U.S. Nuclear Regulatory Commission F and H Area Tank Farms Monitoring Activities (Memo to A. White of U.S. DOE from L. B. Romanowski).” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. June 10, 2020. [ADAMS Accession No. ML20279A785]</u>

This transmittal memo provided follow-up information in response to U.S. NRC’s documentation request concerning Tank 12H and 16H grouting operations. It listed the documentation and information that had been requested and provided some of the requested information in either the memo itself, or in attachments to the memo. Attachment 1 was a diagram of riser penetrations, noting any equipment installed in each riser, in Tank 12H. Attachment 2 was a similar diagram noting risers in which video-camera equipment was installed. Attachment 3 was a diagram of the grouting slickline layout. Five accepted and five rejected Tank 12H grout batch tickets transmitted as Attachments 4 and 5 to the memo were illegible; legibility could not be improved with image-sharpening techniques. Attachment 6 was a color-coded Tank 12H grouting calendar for days when the primary, annulus, risers, failed and intact cooling coils, and equipment were grouted. Additionally, the transmittal memo was accompanied with a set of requested reports and work orders in electronic copy/PDF format. Items NRC requested but were not transmitted with the memo included Tank 12H grouting operations video (DVDs) and a drawing of the Tank 12H annulus, ventilation ductwork and air supply registers, which was later provided in document SRR-CWDA-2020-00058. In anticipation of grouting-operations video being transmitted to NRC shortly thereafter, DOE included Table 1 in the memo to provide date/time stamp information for specific requested grouting operation activities that NRC staff was interested in monitoring.

<u>SRR-CWDA-2020-00058. Romanowski, L. “Type I Waste Tanks Dehumidification System Heating and Ventilation Ductwork [From Dwg. # W146593].” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. July 8, 2020. [ADAMS Accession No. ML20279A786]</u>

This is a two-page set of four engineering drawings of Type I tank annuli and their dehumidification system heating and ventilation ductwork, which was based on classified drawing #W146593, but modified to only communicate unclassified information and annotated for clarity. This new document was prepared and transmitted in response to a request from NRC staff for DOE to provide a drawing of the Tank 12H internals.

<u>SRR-CWDA-2020-00061. Flach, G.P. “Memorandum: Application of Characterization of the Aqueous and Solid Phase Chemistry of Closure Grouts.” Revision 0. Aiken, South Carolina: Savannah River Remediation. August 25, 2020. [ADAMS Accession No. ML20303A345]</u>

To address uncertainty in realistically achievable E_h ranges for tank grout, Savannah River Ecology Laboratory (SREL) characterized the aqueous chemistry of three candidate tank fill grouts via a series of batch and column studies under a range of atmospheric conditions: (i) LP#8-16, a reducing tank grout referred to herein as Tank Closure Grout (TCG; 18% ordinary Portland cement; 30% ground granulated blast furnace slag; 52% fly ash); (ii) LP#8-16 except slag replaced by fly ash similar to mix ZB-FF-8-D, referred to herein as Tank Closure Grout with No Blast Furnace Slag (TCG-NBFS; 18% ordinary Portland cement and 82% fly ash), and (iii) EXE-X-P-0-X (7.7% ordinary Portland cement and 92.3% fly ash), referred to herein as CLSM (not to be confused with mix ZB-FF-8-D, which is also known as Zero-Bleed CLSM). Test conditions were (i) open, oxidizing atmosphere, (ii) N2-purged atmosphere, (iii) closed, reducing atmosphere. Batch equilibration and column test results (SREL Doc. R-21-0001) are summarized in Table 1 of the report, reproduced next.

Original dry feed cementitious materials, the three candidate reference tank grouts (i.e., unleached), and leached grout samples subjected to various batch equilibration conditions also underwent solid-phase characterization by XRF (as borate fused bead samples) and XRD analyses (SREL Doc. R-21-0001). Resulting empirical grout mineralogy data may be used to test reactivity assumptions for and update mineralogy assumptions in the waste release model. The identified mineral phases are summarized in Tables 2 and 3 of the report, reproduced below. Updates to the tank farm waste release model are anticipated to use these new data to address the (i) impact of infiltrating groundwater on grout pore-water chemistry as a function of time; (ii) anticipated mineral states; and (iii) solubility-controlling mineral phases selected per element.

The report concludes that the open-atmosphere and nitrogen-purge leaching conditions comprise reasonable upper and lower E_h endpoints for realistic field conditions inside waste storage tanks, and that this range is smaller than previously considered in SRNL-STI-2012-00404, which could affect radionuclide solubilities used in future PA modeling. Additionally, the report also concluded that E_h > 0.45 V is not realistic, but that a limit of ~0.35 V was supported by observations, suggesting that Pu solubility should be limited in Region II conditions. Further, the report concluded that E_h less than −0.29 V cannot be achieved with reducing tank grout/TCG; in this study, the lowest E_h achieved for TCG under nitrogen atmosphere conditions was −0.12 V, similar to a previously observed low E_h of −0.07 V (SRR-CWDA-2016-00086). There is little solubility control of Tc at E_h greater than −0.1 V in Reduced Region II conditions. Finally, the report concludes that under realistic, open atmosphere conditions, reducing tank grout/TCG E_h observed was ≤0.26 V at ≤150 days, consistent with similar values previously assumed for Oxidized Region II and Region III (SRNL-STI-2012-00404). Longer oxygen exposure may result in higher Eh for reducing tank grout. For non-slag-bearing candidate tank grouts TCG-NBFS/ZB-FF-8-D and EXE-X-P-0-X, however, E_h was observed ≤0.35 V.

While E_h > 0.24 V does not increase Np solubility in Region II, E_h = 0.35 V does increase Np solubility in Region III. Therefore, Np solubility for Region III will likely be increased in PA modeling for any waste storage tanks filled with a non-slag-bearing, non-reducing grout. The report recommended a general reanalysis of realistic E_h assumptions be conducted, especially for modeling Tc and Np solubilities.

Table 1: Summary of Batch Equilibration Results (SREL Doc.: R-21-0001) Compared to Geochemical Modeling Values for Reducing Grouts (SRNL-STI-2012-00404; SRR-CWDA-2016-00086)

	pH	Eh (volts)	Ca^{2+} (molar)	Na^{+} (molar)	Mg^{2+} (molar)	K^{+} (molar)
Leaching solution prescribed in SRNL-STI-2012-00404						
	4.68		2.1E-06	8.7E-06	1.3E-06	
Chemical Conditions of Reducing Grout Pore Water (SRNL-STI-2012-00404; SRR-CWDA-2016-00086)						
Red. Region II	11.1	-0.47	4.0E-03	1.0E-03		
Ox. Region II	11.1	0.56	4.0E-03	1.0E-03		
Ox. Region III	9.2	0.68	6.6E-05	1.0E-03		
Test Conditions			Current Study			
Batch Test - Open Atmosphere*	pH Range	Eh Range (Volts)	Ca^{2+} (molar)	Na^{+} (molar)	Mg^{2+} (molar)	K^{+} (molar)
TCG	11.1-12.6	0.12-0.26	2.0E-04	2.3E-04	3.6E-06	7.1E-04
TCG-NBFS	10.1-12.4	0.16-0.28	3.1E-04	2.2E-04	6.0E-06	8.2E-04
CLSM	9.2-11.9	0.20-0.35	3.5E-04	1.0E-04	1.1E-05	2.3E-04
Batch Test - N_2 Purged Atmosphere						
TCG	12.1-12.7	(-0.12)-0.18	ND	ND	ND	ND
TCG-NBFS	11.5-12.2	0.003-0.22	ND	ND	ND	ND
CLSM	10.8-11.8	0.02-0.27	ND	ND	ND	ND
Batch Test Coy Chamber - Reducing Atmosphere*						
TCG	11.6-12.8	(-0.42)-0.16	2.8E-04	1.3E-04	1.6E-06	4.3E-04
TCG-NBFS	11.0-12.4	(-0.36)-0.23	5.8E-05	2.3E-04	5.3E-07	1.2E-03
CLSM	9.22-12.1	(-0.45)-0.30	3.1E-04	1.1E-04	4.5E-06	3.4E-04
Column Test - Open Atmosphere**						
TCG	11.3-12.5	0.01-0.26	3.4E-04	6.0E-05	4.5E-07	7.3E-05
TCG-NBFS	10.9-12.3	0.13-0.35	7.7E-04	7.3E-05	1.8E-06	1.7E-04
CLSM	10.7-11.9	0.17-0.35	7.5E-04	5.6E-05	3.4E-06	8.8E-05
Column Test - N_2 Purged Atmosphere**						
TCG	11.3-12.5	(-0.03)-0.17	9.1E-04	6.5E-05	7.0E-07	1.1E-04
TCG-NBFS	11.0-12.1	0.10-0.25	8.0E-04	5.8E-05	1.4E-06	1.3E-04
CLSM	10.6-12.0	0.13-0.31	6.1E-04	4.9E-05	2.1E-06	1.0E-04

*Cation data for batch tests reflect the final solution after the "enhanced leaching" treatment.
**Cation data for column experiments reflect the final effluent composition.

Table 2: Summary of Mineral Phases Identified Through XRD.

PHASE	SAMPLES OBSERVED IN			CONFIDENCE LEVEL
	CLSM	TCG-NBFS	TCG	
Strätlingite *$Ca_2Al_2SiO_7.8H_2O$*	• CLSM-REF • CLSM-OPEN • CLSM-CLOSED • CLSM-N_2	• TCG-NBFS-REF • TCG-NBFS-OPEN • TCG-NBFS-N_2	• TCG-REF • TCG-OPEN • TCG-CLOSED • TCG-N_2	HIGH
Ettringite *$Ca_6Al_2(SO_4)_3(OH)_{12}(H_2O)_{26}$*	• CLSM-REF	• TCG-NBFS-REF	• TCG-REF	HIGH
Kuzelite *$Ca_2Al(SO_4)_{0.5}(OH)_6(H_2O)_3$*	• Not Observed	• Not Observed	• TCG-REF • TCG-OPEN • TCG-CLOSED • TCG-N_2	MEDIUM
Calcium Iron Oxide Sulfite Hydrate *$Ca_4Fe_2O_6(SO_3).12H_2O$*	• Not Observed	• Not Observed	• TCG-REF • TCG-CLOSED • TCG-N_2	LOW
Calcium Aluminum Silicate Hydrate *$CaAl_2Si_7O_{18}.1.7H_2O$*	• Not Observed	• TCG-NBFS-REF	• Not Observed	LOW
Calcium Aluminum Oxide Carbonate Sulfate Hydroxide Hydrate *$3CaO.Al_2O_3.0.17CaSO_4.0.5Ca(OH)_2.0.33CaCO_3.xH_2O$*	• CLSM-REF	• Not Observed	• TCG-REF • TCG-OPEN	LOW
Calcium Aluminum Carbonate Hydroxide Hydrate (Hemicarboaluminate) *$Ca_2Al(CO_3)_{0.25}(OH)_{6.5}(H_2O)_2$*	• CLSM-REF	• TCG-NBFS-REF	• TCG-REF	MEDIUM
Calcium Aluminum Iron Oxide Carbonate Hydroxide Hydrate *$Ca_8Al_2Fe_2O_{12}CO_3(OH)_2.22H_2O$*	• CLSM-REF	• TCG-NBFS-REF • TCG-NBFS-CLOSED • TCG-NBFS-N_2	• TCG-OPEN • TCG-CLOSED • TCG-N_2	LOW
Hydrotalcite *$Mg_{0.67}Al_{0.33}(CO_3)_{0.17}(OH)_2(H_2O)_{0.5}$*	• Not Observed	• Not Observed	• TCG-REF • TCG-OPEN • TCG-CLOSED • TCG-N_2	MEDIUM
Calcium Aluminum Carbonate Hydroxide Hydrate (Monocarboaluminate) *$Ca_4Al_2(CO_3)(OH)_{12}(H_2O)_5$*	• CLSM-REF	• TCG-NBFS-REF • TCG-NBFS-CLOSED • TCG-NBFS- N_2	• Not Observed	MEDIUM
Mullite *General: $3Al_2O_3.2SiO_2$* *Actual: $Al_2(Al_{2.588}Si_{1.412})O_{9.706}$*	• All Samples	• All Samples	• All Samples	HIGH
Portlandite *$Ca(OH)_2$*	• Not Observed	• Not Observed	• TCG-REF • TCG-OPEN • TCG-CLOSED • TCG-N_2	MEDIUM
Quartz *SiO_2*	• All Samples	• All Samples	• All Samples	HIGH
Calcite *$CaCO_3$*	• All Samples	• All Samples	• All Samples	HIGH
Hematite *Fe_2O_3*	• All Samples	• All Samples	• All Samples	HIGH
Silicon *Si*	• All Samples	• All Samples	• All Samples	HIGH
Calcium Silicate Hydrates *C-S-H*	• Possibly present in all samples but most predominant in TCG-REF			MEDIUM
Magnetite *Fe_3O_4*	• All Samples	• All Samples	• All Samples	HIGH

Table 3: Summary of Rietveld Quantification Results for the Three Pastes.

CLSM Sample	Phase (wt%)									
	Amorphous	*Mullite*	*Quartz*	*Hematite*	*Magnetite*	*Calcite*	*Strätlingite*	*Ettringite*	*Hemicarbo-aluminate*	*Monocarbo-aluminate*
REF (Non-Leached)	66.12	14.11	10.23	2.09	1.10	0.88	2.72	0.49	1.88	0.38
OPEN	65.55	14.75	10.95	2.12	1.48	3.01	2.14	-	-	-
CLOSED	68.79	14.75	11.19	2.12	1.64	1.51	Trace *	-	-	-
N_2	66.92	15.24	11.24	2.14	1.69	1.10	1.71	-	-	-

* Trace is indicated for strätlingite because the peak is barely above background and its inclusion (at such low concentrations) for Rietveld refinement resulted in pattern simulation anomalies; hence it was omitted during Rietveld quantification

TCG-NBFS Sample	Phase (wt%)									
	Amorphous	*Mullite*	*Quartz*	*Hematite*	*Magnetite*	*Calcite*	*Strätlingite*	*Ettringite*	*Hemicarbo-aluminate*	*Monocarbo-aluminate*
REF (Non-Leached)	66.97	11.69	8.64	1.79	0.99	2.63	1.85	1.41	2.61	1.43
OPEN	68.66	11.87	9.07	1.81	1.01	6.08	1.51	-	-	-
CLOSED	72.58	11.32	9.12	1.73	1.07	2.79	-	-	-	1.39
N_2	71.17	11.77	8.55	1.86	0.79	2.27	1.75	-	-	1.84

TCG Sample	Phase (wt%)											
	Amorphous	*Mullite*	*Quartz*	*Hematite*	*Magnetite*	*Calcite*	*Ettringite*	*Strätlingite*	*Hydrotalcite*	*Kuzelite*	*Portlandite*	*Hemicarbo-aluminate*
REF (Non-Leached)	78.40	6.06	5.44	1.22	0.14	1.14	0.91	Trace *	1.42	0.78	0.42	4.07
OPEN	77.85	6.55	5.64	1.30	0.22	5.37	-	Trace	2.67	0.41	-	-
CLOSED	78.92	5.48	5.28	1.29	0.15	3.38	-	Trace	3.07	1.75	0.08	-
N_2	79.66	6.64	5.96	1.44	0.24	1.30	-	Trace	2.78	1.77	0.20	-

* Trace is indicated for strätlingite because the peak is barely above background and its inclusion (at such low concentrations) for Rietveld refinement resulted in pattern simulation anomalies; hence it was omitted during Rietveld quantification.

<u>VSL-14R3330-1. Papathanassiu, A.E. et al. "Saltstone Clean Cap Grout Assessment (Final Report)." Revision 0. Washington, DC: Vitreous State Laboratory, The Catholic University of America. March 2014. [ADAMS Accession No. ML20279A790]</u>

This report documented the fresh grout properties of candidate formulations for clean cap grout. The original clean cap grout formulation had the same water-to-premix (*w:p*) ratio as the saltstone mix, i.e., *w:p* = 0.6, but *w* was only water and not saltstone solution. Ultimately, two new clean cap grout mixes employing a 45 percent Holcim GranCem® Grade 100 slag cement (d_{50} = 13 µm) to 45 percent fly ash to 10 percent Portland cement blend were recommended for use to reduce bleed-water production and enhance bleed-water reabsorption. One alternative mix reduced the *w:p* ratio to 0.5 and exhibited 40 percent less bleed water production; the other mix also reduced *w:p* to 0.5, and added caustic sodium hydroxide (NaOH) at 1.6 M to the water, which is comparable to that in the salt solution, to reduce bleed-water production by 60 to 80 percent. These new clean cap grout formulations exhibited acceptable slump flows (ASTM

C1611/C1611M, 2018) from 90.2 to 67.6 cm (35.5 to 26.6 in), respectively, and had sufficiently long set times (>10 hrs) that would enable off-site production. Testing of clean cap grout comprised of finer Grade 120 slag cement by Lafarge (d_{50} = 8.5 μm) or MC-500 Microfine Cement ultrafine slag cement by de Neef Chemicals/Grace Construction Products (d_{50} = 3.5 μm) was undertaken to understand the impact of slag particle size on bleed-water production because finer particles were expected to increase reactivity as a result of their enhanced surface area, and thereby promote hydration. The authors found that decreased slag particle size led to increased bleed-water production unless caustic sodium hydroxide (NaOH) aqueous solution was used. Two types of high-range water reducers or superplasticizers were also tested, including ADVA Cast 575, which is also used to batch SRS's reducing tank grout. The authors observed that use of ADVA Cast 575 as a water-reducing admixture significantly increased bleed-water production and rapid segregation of most of the grout solids from the liquid mass. Appendix A of the report reproduces material certification reports and specifications for the various cementitious materials and admixtures tested. The authors anticipated potential vendor reluctance to introduce caustic sodium hydroxide (NaOH) into clean cap grout at either an offsite mixing facility or mixer trucks, so although clean cap grout behavior and performance would improve, future implementation is thought to be unlikely. This report does not address the potential performance of clean cap grout that might be comprised of Lehigh Grade 120 slag cement, which is now in use at SRS.

<u>VSL-15R3740-1. Gong, W. et al. "Investigation of Alternate Ground Granulated Blast Furnace Slag for the Saltstone Facility (Final Report)." Revision 0. Washington, DC: Vitreous State Laboratory, The Catholic University of America. August 26, 2015. [ADAMS Accession No. ML16117A355]</u>

This report describes testing conducted for SRR to assess characteristics of grout specimens prepared using alternative slag cements for use in saltstone, tank grout, and Saltstone Disposal Structure concrete at SRS, given that Holcim's Grade 100 slag would no longer be produced. The report states that Grade 120 slags are now more widely available than Grade 100 slags, and that "the strength differential between the Grade 100 and 120 is provided by the smaller particle size and enhanced reactivity of the higher Grade slag." In general, substituting a Grade 120 slag for Grade 100 should result in higher compressive strength and lower saturated hydraulic conductivity grout if the Grade 120 slag has a finer particle size and enhanced reactivity. Differences in slag chemistry may also impact fresh and hardened properties of cementitious grouts, which could affect long-term performance. Four alternative slag mixes of saltstone simulant were tested, along with the original Holcim Grade 100 slag cement mix, for granulometry, reductive capacity, viscosity, yield stress, temporal gelation behavior (i.e., "gel time" at which point a grout slurry is no longer pourable), and heat of hydration (through the first 12 days post-placement). The saltstone simulants produced with the five slags had broadly similar properties, especially those produced with Holcim, Lafarge, and Lehigh Hanson slags; therefore, the Lafarge and Lehigh Hanson slags were the two best options for replacing Holcim's Grade 100 slag with minimal impact to performance. The Lehigh Hanson Grade 120 slag had the highest reduction capacity (12 percent greater than Holcim Grade 100) and the lowest heat release of all five slags, making it the clear choice to replace the Holcim Grade 100. The authors maintained that substituting Grade 120 slag for Grade 100 slag would result in a higher compressive strength grout due to enhanced surface area (i.e., smaller particle size) and reactivity, but saltstone simulant specimens that resulted from this work were not tested for compressive strength, so this statement could not be verified. It is also notable that the mean particle size for Holcim Grade 100 slag is smaller in this report (d_{50} = 16.05 μm) and even smaller in the aforementioned VSL-14R3330-1 report (d_{50} = 13 µm) than the Lehigh Grade 120 slag (d_{50} = 18.47 µm), but the authors do not dwell on this unanticipated finding that Grade 100 slag may have a finer mean diameter than Grade 120 slag (the most relevant portion of their Table 5.5 and their Figure 5.10a illustrating the particle size distributions of the alternative slags are reproduced next). The impact of slag particle size variability on compressive strength, saturated hydraulic conductivity, and chemical reactivity of the reducing tank grout is uncertain, as is the extent to which slag particle size from a given slag manufacturer varies with time.

Table 5.5. Characteristics of GGBFS Materials for Preparing Saltstone Grout Samples.

GGBFS Type	Mill Report Data			VSL Determined Slag Characteristics		
	Activity Index	Sulfide	Blaine fineness (m^2/kg)	Vol. % Particles Passing 22 µm	Mean Particle Size, µm	Reduction Capacity, µeq/g
Holcim Slag Grade 100	116	1.0%	643	78.72	16.05	722
Lehigh Slag Grade 120	124	0.9%	539	73.39	18.47	812

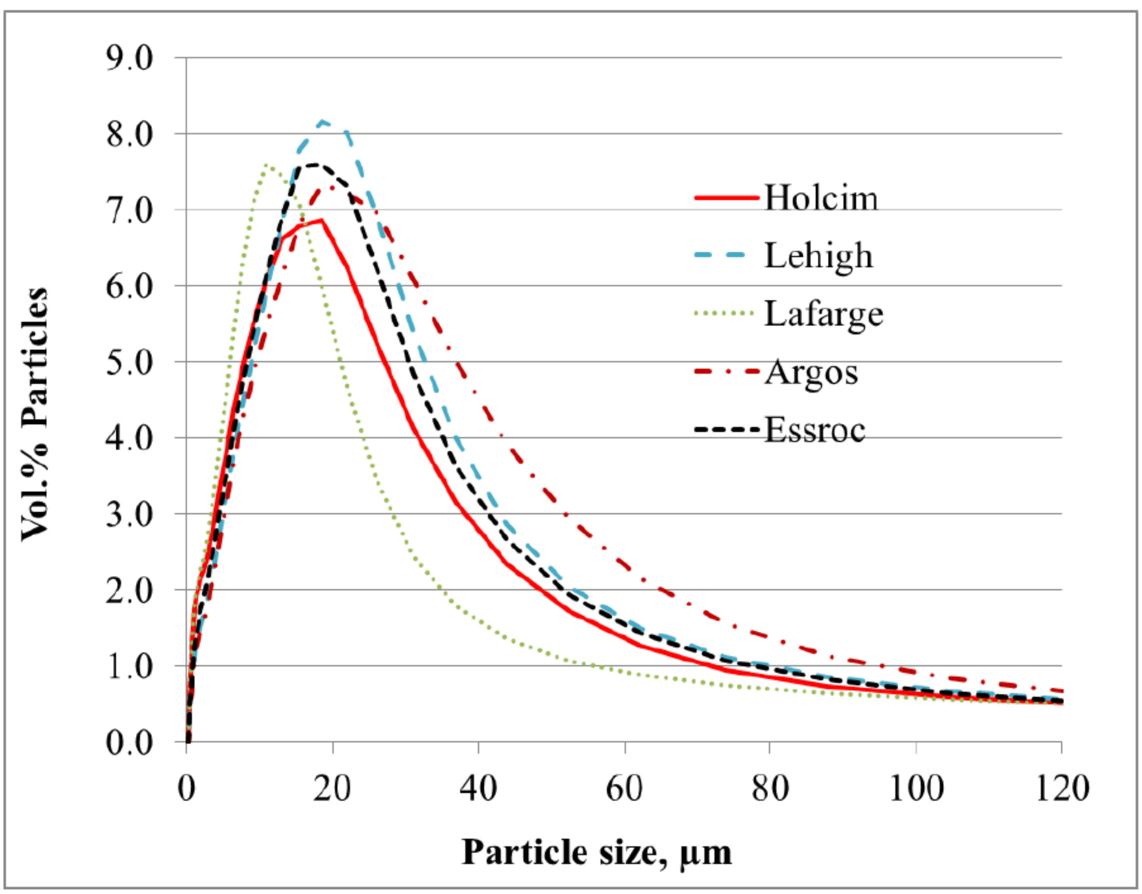

Figure 5.10a. Particle size distributions of various GGBFS materials in terms of volumetric statistics.

Summaries of Tank 12H Documents:

HTF-SKM-2015-00010. “Tank 12 Flush & Grout Fill Configuration Intact Coils [WO] 1337683-31 (2 Sheets).” Revision B. Closure Engineering, Savannah River Site, Aiken, South Carolina, October 28, 2015. [ADAMS Accession No. ML20279A781]

This two-sheet document of engineering drawings (or “sketches”) is an attachment to Work Order (WO) No. 1337683-31. Sketch notes indicate that initial intact-coil flushwater is sent to Tank 10H, Riser 3, and then a gray-water collection tote receives coil-water after flushing is completed, and the water-to-grout transition interface. Sketches illustrate (i) the flushwater supply, (ii) flushwater manifold, (iii) grout-pumping system, (iv) flushwater supply apparatus, (v) return gray-water apparatus, (vi) return flushwater apparatus, (vii) Tank 10H, Riser 3 flushwater apparatus, and a (viii) 1,136 L (300 gal) gray-water tote.

HTF-SKM-2015-00021. “Tank 12 Grout Placement Plan – Sketch 1 (Associated with WO 01337683-33).” Revision 0. Savannah River Site, Aiken, South Carolina, 2015. [ADAMS Accession No. ML20279A782]

This sketch is an attachment to Work Order (WO) No. 01337683-33; it illustrates the nine lifts/placements of grout that were originally anticipated to be placed into the tank primary and annulus in numerical order. It also illustrates a tank riser and an annulus riser and their positions with respect to Grade level and the tank ceiling, the tremie attachment point (with its cam-lok coupling), the grout slickline connection point, and riser cover ports. A note on the sketch indicates the tremies used are all released into either the primary or the annulus.

SRR-CWDA-2015-00074. “Addendum to the *Industrial Wastewater Closure Module for Liquid Waste Tank 12H H-Area Tank Farm, Savannah River Site, SRR-CWDA-2014-00086, Revision 0, May 2015*.” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. October 2015. [ADAMS Accession No. ML15294A364]

This report documented the final Tank 12H inventory characterization information for residual waste material remaining in the tank. SCDHEC’s conditional approval of the original closure module and its approval of this closure module addendum, represented SCDHEC’s ultimate agreement that waste-removal activities for Tank 12H could cease, and it authorized stabilization of Tank 12H and its residual contaminants via grouting under Construction Permit #17,424-IW. DOE’s conclusions in the Tank 12H closure module were not changed in the addendum.

SRR-CWDA-2016-00068. “Tank 12 Final Configuration Report for H-Tank Farm at the Savannah River Site.” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. December 2016. [ADAMS Accession No. ML18235A409]

This report documented Tank 12H isolation, data obtained from the grouting of Tank 12H, and it clarified exceptions that occurred relative to the planned configuration described in the closure module (SRR-CWDA-2014-00086). Data presented included grouting operation dates, average 28-day compressive strength test results obtained from tank grout test cylinders, and bulk grout fill, cooling coil grout fill, and equipment grout fill volume calculated actuals versus pre-estimates. Due to discrepancies between the closure module description and the actual closure process, the report also clarified the nature of equipment remaining in Tank 12H that was filled with grout.

DOE reported average compressive strength test results from a total of 205 ASTM C39 test cylinders. The 28-day post-casting compressive strength average was 16,430 kPa (2,383 psi or 164 bars). DOE also reported that the volume of reducing grout to be placed inside the primary was pre-estimated at 3,000 cubic meters (3,927 cubic yards), while the calculated volume of reducing grout actually placed in the primary (based on the number of concrete mixing trucks discharged and a nominal volume of grout dispensed per truck) was 2,971 cubic meters (3,887 cubic yards), which is 99 percent of the estimate. Likewise, the estimated volume of reducing grout required to fill the annulus was 446 cubic meters (583 cubic yards) compared to an actual volume placed of 468.7 cubic meters (613 cubic yards). Finally, 34.4 cubic meters (45 cubic yards) of reducing grout were estimated as needed to fill Tank 12H risers, whereas 19.9 cubic meters (26 cubic yards) were placed.

SRR-CWDA-2018-00047. "Savannah River Site F and H Area Tank Farms, NRC Onsite Observation Visit: 'Tank 12 Grouting Calendar (Slide 21).'" Revision 1. Aiken, South Carolina: Savannah River Remediation, LLC. 13–14 August 2018. [ADAMS Accession No. ML18247A080; see also SRR-CWDA-2020-00052, Attachment 6].

Grouting operations at Tank 12H began on January 19, 2016, and were completed on April 27, 2016, with the exception of a spray chamber above Riser 5 that was grouted on May 2, 2016 (SRR-LWE-2016-00036). Tank primary grouting began on January 19, 2016, and ended on March 7, 2016. Annulus grouting began on February 8 and ended on March 1, 2016. Failed cooling coil grouting began on January 26 and ended on January 29, 2016. Intact cooling coil grouting began on March 17 and ended on March 21, 2016. Riser grouting began on April 5 and ended on April 27, 2016 (SRR-CWDA-2020-00052, Attachment 6).

SRR-LWE-2014-00162. Voegtlen, R.O. "Video Inspection Plan for Tank 12 During Tank Grouting Activities (Interoffice Memorandum)." Revision 0. Aiken, South Carolina: Savannah River Remediation. February 12, 2015. [ADAMS Accession No. ML22056A507]

This memorandum describes the video inspection plan for monitoring the grouting of Tank 12H, including its primary, annulus, and in-tank equipment to be abandoned in place. Following bulk waste removal, residual waste-incidental-to-reprocessing was approximately 5,678 L (1,500 gal) in the heel of the primary, 1,514 L (400 gal) on cooling coils in the primary, and 114 L (30 gal) in the annulus. Equipment to be grouted in place or entombed in grout includes an abandoned transfer jet in Riser 6, a submersible transfer pump in Riser 7, an abandoned dewatering pump in the central riser, a robotic sampling crawler near Riser 4 and the west wall of the valve house, and an annulus jet in the North Riser. Tank primary and annulus baseline inspections were performed with one video camera moved from riser to riser to verify and document the presence of expected in-tank equipment within 30 days prior to commencement of grouting operations. The video record of the inspections was provided to RM&A. During grouting operations, video cameras were installed in Risers 1, 3, 5, and 8 to monitor (i) grouting of the tank primary and abandoned equipment, (ii) tremies during operation and disconnection, (iii) grout level based on landmarks/abandoned equipment, and (iv) discharge of line-clearing pigs. The video cameras were to focus significant attention on the grout/tank wall interface. Video cameras were also installed in the East and West Risers of the annulus to monitor (i) grout discharged from the tremies and flowing in the annulus, (ii) tremies during operation and disconnection, (iii) grout level based on landmarks/abandoned equipment, and (iv) discharge of line-clearing pigs. Inspections to look for grout anomalies using video cameras occurred at least three times on grouting days, at the beginning, middle and end of a 7am to 5pm shift. Video monitoring was to occur continuously during a grouting shift, and especially during line-clearing operations.

Video inspections and monitoring were to be documented and maintained as permanent DVD records. Grouting activity information was entered into a log with date and time correlating to the date/time on the video.

SRR-LWE-2016-00020. Voegtlen, R.O. “Tank 12 Grout Cracks under Riser 1,” Revision 0. Savannah River Remediation: Aiken, South Carolina. 23 February 2016. [ADAMS Accession No. ML22056A508]

This single-page note-to-file documented that a video camera inspection performed on Monday, February 22, 2016, identified small surface cracks in the previously placed tank grout beneath Riser 1 of Tank 12H. RM&A was notified, and a meeting was held to discuss the cracks that morning. Persons present at the meeting were John Occhipinti, Andy Tisler, Steve Thomas, Mark Layton, Steve Simner, Bruce Martin, and Bob Voegtlen. The cracks were described as emanating in a circle from under the riser near where pigs entered the tank. Based on previous tank grouting activities performed for Tanks 18, 19, 5, 6, and 16, the observed cracking was deemed rare. The note concludes that because the cracks were limited to this single location and only observed once, they should have minimal impact on “hydraulic modeling,” and grouting of the Tank 12H primary was allowed to proceed.

SRR-LWE-2016-00036. Voegtlen, R.O. “Tank 12 Final Configuration Report Inputs (Interoffice Memo).” Revision 2. Aiken, South Carolina: Savannah River Site. December 6, 2016. [ADAMS Accession No. ML20279A787]

This report compiles and documents data from the grouting of Tank 12H. A deviation from the grouting configuration described in SRR-CWDA-2014-00086 is included. Dates when the various grouting operations began and ended are included. Report is referenced extensively in the main body of this technical review report.

SRR-TCR-2016-00007. Davis, B. “Tank 12 Grouting Liquid Spill Lessons Learned.” Aiken, South Carolina: Savannah River Remediation, LLC. May 9, 2016. [ADAMS Accession No. ML20279A788]

This memo documented lessons learned from a Tank 12H liquid spill that occurred during the final stages of grouting of the tank primary. Ten items were identified in a table in the appendix to the memo, including recommendations to (i) reevaluate the costs–benefits of removing spray chambers from risers used to grout future tanks because the presence of the spray chambers makes video-camera monitoring of grout levels in the risers difficult; (ii) provide a grouting termination plan in future work orders to control grout and/or liquid levels in risers so that liquid does not overflow risers and spill onto the tank top; (iii) provide grout spill plan in work orders to prepare and locate spill kits near risers being grouted to minimize the impact and spread of any spill; (iv) provide an approved plan for placing dry grout mix into risers containing free liquid (e.g., bleed water) to assimilate/absorb the liquid; (v) evaluate alternatives for wetting the grouting slickline other than adding 95 to 189 L (25 to 50 gal) water to the line, which is then disposed of inside the tank; (vi) schedule grout placements with more time elapsed between lifts to allow free liquid assimilation into previous grout pours; in particular allow a significant amount of time to elapse after grouting failed cooling coils, which may add several thousand gallons of free liquid to the tank; (vii) prepare work orders to remove accumulated liquid from the risers via pumping with the assumption that liquid removal will be considered a non-waste transfer; (viii) evaluate the specific configuration and condition of individual risers for characteristics that might make them more likely to create a spill situation and adapt work order development accordingly; (ix) evaluate the costs–benefits of preparing all tank risers with a grout plate to allow insertion of video cameras to monitor rising liquid levels during grouting (DOE thinks the liquid spill onto Tank 12H came from a riser that was not being monitored by camera); and (x) evaluate the use of non-video instruments, such as liquid-level indicators, that will sound an alarm when a threshold liquid level is exceeded.

WO 01337683-31. Alexander, O. "TK.12 Flush & Grout Intact Chromate Cooling Coils." Revision 1. November 2, 2015 [Initials and handwritten notes added during March 2016]. [ADAMS Accession No. ML20279A791]

This work order is for flushing contaminants inside intact Tank 12H chromate cooling water coils to Tank 10H, Riser 3, and for grouting intact coils. The work order describes personal protective equipment (PPE) used, and for which steps each PPE is used, lists chemicals employed, checklists for steps to be taken before and during the flushing and grouting processes, and the steps to be taken if deviations are required.

WO 01337683-31-A. "Attachment 'A' – Tank 12 Coil Flushing Spreadsheet." [ADAMS Accession No. ML20279A792]

This work order attachment identified the 8 intact cooling coils flushed and grouted in Tank 12H (i.e., CRW-CCL-4, -17, -18, -22, -23, -30, -31, and -32), and recorded water levels before and after flushing, and the required flush volumes per coil (i.e., 94, 116, 147, 94, 104, 102, 112, and 102 gal). The spreadsheet did not include the dates upon which flushing occurred.

WO 01337683-31-F. "Attachment F – Coil Grout Spreadsheet." [ADAMS Accession No. ML20279A794]

This work order attachment identified 5 of the 8 intact cooling coils flushed and grouted in Tank 12H (CRW-CCL-4, -17, -18, -22, and -23), and the "100 percent" coil capacity (i.e., volume) of these coils (i.e., 102, 124, 154, 102, and 109 gal). Grouting of CRW-CCL-17 occurred on March 4, 2016, so its flushing must have predated the flushing of all other intact coils. Other coils were known to have been flushed on March 16, 2016, and then grouted on either March 17 or 21, 2016. During an April 28, 2022, follow-up teleconference (ADAMS Accession No. ML22131A348), DOE indicated that they would send NRC a missing page from this work order attachment (ADAMS Accession No. ML22131A348, response to Q21). The missing page was provided later in SRMC-CWDA-2023-00074 and provides information for intact cooling coils CRW-CCL-30, -31, and -32.

WO 01337683-33. Patton, G.W. "Placement of Bulk Fill Grout (Tank 12 Work Order)." Revision 2. [ADAMS Accession No. ML20279A795]

This work order is for placing grout in Tank 12H in support of tank closure, including operations such as removal of riser cover port plugs, tremie installation into risers and pumping of grout through slickline piping. Nine grout placements (i.e., lifts) are described, including their not-to-exceed volumes, necessary to fill the primary tank, annulus, and annulus inlet ventilation horizontal and vertical duct, and additional placements for each riser and riser cap (including annulus exhaust duct). The work order describes personal protective equipment (PPE) used, and for which steps each PPE is used, lists chemicals employed, checklists for steps to be taken before and during the grouting process, and the steps to be taken if deviations are required.

WO 01337683-33-A. “Attachment A – Tank 12 Tremie Installation Steps.” [ADAMS Accession No. ML20279A796]

This work order attachment is for installation of tremies used to place grout in the Tank 12H primary and annulus through risers, including operations such as removal of riser cover port plugs and installation of hammer valves. Checklists for steps to be taken during the processes are provided.

WO 01337683-33-B. “Attachment B – Tank 12 Cleaning/Pigging of Slickline.” [ADAMS Accession No. ML20279A797]

This work order attachment is for implementation at any time during grouting operations when it is deemed necessary to clean out the grout slickline. Checklists for steps to be taken during the process are provided.

WO 01337683-50. Alexander, O. “TK12 Grout Failed Coils.” August 12, 2015. [ADAMS Accession No. ML20279A798]

This work order is for grouting failed Tank 12H chromate cooling water coils. The work order describes personal protective equipment (PPE) used, and for which steps each PPE is used, lists chemicals employed, checklists for steps to be taken before and during the grouting process, and the steps to be taken if deviations are required.

WO 01337683-51. Patton, G.W. “TK 12 Closure Constr Perform Equipment.” [ADAMS Accession No. ML20279A799]

This work order is for construction to perform grouting of equipment for Tank 12H at the Riser 1, Riser 3, Riser 5 and Riser 8 spray chambers; Riser 2 steam jet (core), steam jet (jacket), and transfer line; North annulus conductivity probe #1 and #2 and South annulus conductivity probe #1 and #2; Riser 7 submersible transport pump, caisson lance, thermowell, and Riser 4 reel tape, HLLCP, TW insert plug, spray lance, and H&V riser drain. The work order describes personal protective equipment (PPE) used, and for which steps each PPE is used, lists chemicals employed, checklists for steps to be taken before and during the grouting process, and the steps to be taken if deviations are required.

Summaries of Tank 16H Documents:

2015-NCR-15-WHC-0008. Redwood, A.R. “Nonconformance Report No. 2015-NCR-15-WHC-0008.” Aiken, South Carolina. August 20, 2015. [ADAMS Accession No. ML20302A273]

This nonconformance report addresses disposition of curing-temperature nonconformances for 12 lab numbers associated with Tank 16H grout compressive strength cylinders that would later be tested for 7- and 28-day compressive strength. According to specification C-SPP-F-00055 and ASTM C31 paragraph 10.1.3.1, the cylinders should be held at a laboratory temperature of 73.5 ± 3.5 °F, but due to equipment failure, the room temperature rose to 78.5 °F for a period of 2 hrs on June 17, 2015, for cylinders associated with lab numbers 150102, 150103, 150104, 150105, 150106, 150107, 150113, 150114, 150115, 150116, 150119, and 150120. The NCR indicated that the laboratory temperature exceeded the upper end of the intended temperature range by 1.5 °F for 2 hrs. The Concrete Test Report for lab number 150103 indicates that three of five 28-day compressive strength tests conducted on June 30, 2015, plus the overall average value, did not meet the 13,800 kPa (2,000 psi or 138 bar) compressive strength threshold, and the Concrete Test Report for lab number 150120 indicates that one of three 28-day compressive strength tests, conducted on July 14, 2015, did not meet the 13,800 kPa (2,000 psi or 138 bar) compressive strength threshold, although the average compressive strength did meet the threshold. Initially, the field engineering disposition recommendation errantly indicated that all the 28-day breaks exceeded the design requirement compressive strength, and that the disposition recommendation was to “use-as-is.” Later, the document acknowledged that some cylinder breaks conducted on June 30 and July 14, 2015, exhibited compressive strengths below the design requirement of 13,800 kPa (2,000 psi or 138 bar), but stated that the “results are within the tolerances of the applicable testing standards ASTM C94 and ACI 301…and as such comply with the strength requirement of specification C-SPP-F-00055.” The curing temperature and tolerance prescribed are meant to ensure that accurate compressive strength data are obtained from cylinder break tests. Most of the break tests appended to this NCR indicated that compressive strengths of this reducing tank grout, which was placed into Tank 16H, exceeded the minimum compressive strength design requirement.

<u>2015-NCR-15-WHC-0013. Redwood, A.R. “Nonconformance Report No. 2015-NCR-15-WHC-0013.” Aiken, South Carolina. October 20, 2015. [ADAMS Accession No. ML20302A274]</u>

This nonconformance report addresses disposition of curing-temperature nonconformances for 31 lab numbers and associated Tank 16H grout compressive strength cylinders that would later be tested for 7- and 28-day compressive strength. According to specification C-SPP-F-00055 and ASTM C31 paragraph 10.1.3.1, the cylinders should be held at a laboratory temperature of 73.5 ± 3.5 °F, but due to equipment failure, the room temperature rose to 79 °F for a period of 5 hrs on July 19, 2015, affecting cylinders associated with lab numbers 150127, 150128, 150130, 150131, 150132, 150133, 150134, 150135, 150140, 150141, 150143, 150144, 150145, 150146, 150148, 150149, 150152, 150153, 150156, 150157, 150158, 150159, 150162, 150163, 150166, 150167, 150169, and 150170, and again the room temperature rose to 79 °F for a period of 9 hrs on July 27, 2015, followed by another 6 hrs at 78.5 °F on July 28, 2015, affecting lab numbers 150140, 150141, 150143, 150144, 150145, 150146, 150148, 150149, 150152, 150153, 150156, 150157, 150158, 150159, 150162, 150163, 150166, 150167, 150169, 150170, 150171, 150172, and 150173 (see also USQ-HTF-2015-00686). In addition, the room temperature was again out of tolerance at 80.5 °F on July 30, 2015, for 9 hrs, affecting cylinders associated with lab numbers 150148, 150149, 150152, 150153, 150156, 150157, 150158, 150159, 150162, 150163, 150167, 150169, 150170, 150171, 150172, and 150173. The NCR indicated that the laboratory room temperature exceeded the upper end of the intended temperature range by 2.0 °F for 5 hrs on July 19, 2015, by 2.0 °F for 9 hrs on July 27, 2015, by 1.5 °F for 6 hrs on July 28, 2015, and by 3.5 °F for 9 hrs on July 30, 2015. For this NCR, all 28-day breaks exceeded the design requirement of 13,800 kPa (2,000 psi or 138 bars) compressive strength (USQ-HTF-2015-00686), so the construction engineering recommended disposition of the nonconformance was to use the grout that had been placed inside the tank as is (use-as-is).

<u>HTF-SKM-2014-00031. “Tank 16 – Type II – 85’ DIA Grout Placement Plan.” Revision A. [ADAMS Accession No. ML22056A511]</u>

This document is a closure engineering sketch of the 6 grout lifts that were planned to be placed into Tank 16H. The sketch is presented along with the cubic yards (CY) of grout per lift placed into the primary and annulus, as summarized here:

Lift No.	Primary	Annulus	Volume (CY)
1	×		936
2		×	255
3	×		2911
4		×	356
5	×		1768
6		×	72
Primary Total			5615
Annulus Total			683
Tank 16H Total			6298

SDDR No. 13307. Ganguly, A. "Supplier Deviation Disposition Request No. 13307 (Bleeding of Concrete)." Aiken, South Carolina: Savannah River Site. October 28, 2015. [ADAMS Accession No. ML20279A783]

This supplier deviation disposition request was a result of tank closure grout batches that were prepared by Argos for placement into Tank 16H that exceeded the 0.0 percent maximum bleed requirement after 24 hrs, per ASTM C232/C232M-14 and DOE's specification C-SPP-F-00055. The document has two attachments documenting the two highest bleed results, which were 8.9 percent (June 18, 2015) and 3.3 percent (June 19, 2015), but the deviation description states that none of the bleed tests resulted in zero bleed. Argos proposed disposition for the grout was to use-as-is, and their technical justification for this disposition was given as "bleed water shown will be used for the hydration of slag that will peak hydration around 55 days after placement. After full hydration of the cementitious materials, no free water will be present." SRR's final disposition approach for tank closure grout that did not meet the zero-bleed specification was to use-as-is; the justification was that (i) these batches were a "one-time deviation" from the specification requirement; (ii) other performance requirements (compressive strength and slump flow) were met; and (iii) 8.9 percent bleed or less is still considered "low bleed," and that excess bleed water of 8.9 percent or less will be used by the tank closure grout during its long, slow hydration process.

SRR-CWDA-2014-00102. "Disposal of Cooling Coil Grouting Liquid Within Tank 16 (Interoffice Memorandum from M.H. Layton to J. Rush)." Revision 0. Savannah River Remediation. Aiken, South Carolina. 20 November 2014. [ADAMS Accession No. ML22056A506]

This memorandum evaluated proposed disposal of cooling coil grouting liquid within Tank 16 relative to assumptions made in the HTF PA. To account for the potential that residual chromate in Tank 16 cooling coils would enter the tank primary, an additional 6.52 kg (14.37 lbs) of chromium was added to the Tank 16 primary residual inventory in the Tank 16 SA, so was not considered further in this evaluation. This mass of chromium is based upon the 44 cooling coils in the tank primary being filled with chromated water. Proposed disposal of cooling coil grouting liquid in Tank 16 could add 136 L (36 gal) of aqueous solution to Tank 16 per cooling coil, or a total of 5,996 L (1,584 gal) of aqueous solution for all 44 cooling coils, allowing additional water to be present while grout is placed inside the tank, such that a water volume overage may occur in excess of the amount allowed by the grout procurement specification [i.e., >184 L (>48.5 gal) water per cubic yard of grout]. The memo concludes that the additional water disposed of inside the primary would not affect the chemical properties of the grout (e.g., reducing capacity), so would not affect PA assumptions about grout chemical properties (the memo appears to include a typographical error in this section, where it conflates 5,830 L (1,540 gal) of cooling coil grout with 5,996 L (1584 gal) of cooling coil grouting liquid). The proposed disposal of 5,996 L (1584 gal) of cooling coil grouting liquid in Tank 16 could impact the ability of the grout to impart tank stability if the total excess liquid results in a significant water volume overage. However, if liquid additions and rates of addition were controlled so that individual grout lifts would meet grout specifications, stability assumptions in the PA would not be adversely affected. The memo concludes that disposing of cooling coil grouting liquid within the HTF waste tanks is consistent with inputs and assumptions made in the HTF PA, and that such disposal could be accomplished in compliance with performance objectives if liquid additions were controlled such that grout water overage specifications were met. Water overages of up to 3 percent for grout lifts is consistent with assumptions made in the HTF PA.

SRR-CWDA-2015-00100. "Evaluation of the Use of an Alternative Tank 16 Fill Grout (Per Specification C-SPP-Z-00012) (Interoffice Memorandum to G.C. Arthur from M.H. Layton)." Revision 2. Aiken, South Carolina: Savannah River Remediation, LLC. September 1, 2015. [ADAMS Accession No. ML16119A341]

This interoffice memorandum documents an evaluation of the impact of use of a more flowable clean cap grout (i.e., Vault 4 Clean Cap 1) to complete the Tank 16H primary and annulus [approximately 0.6 m (2 ft) of head space, a maximum of 318,000 L (84,000 gal) in the primary and 38,900 L (10,280 gal) in the annulus] instead of LP#8-016 reducing tank grout, which had mounded-up to such a significant degree that it necessitated a more flowable grout to fill what would otherwise be an irregular void space at the top of the tank and concrete vault. The memo acknowledges that clean cap grout may not meet all the assumed mechanical and chemical properties for tank grout as specified in the PA, but nevertheless indicates that the Tank 16H closure performance objectives will be met. The clean cap grout proposed for use (Vault 4 Clean Cap 1, as described in Specification C-SPP-Z-00012, Revision 1; see also ML18311A184) was used in the SRS Saltstone Disposal Facility. The memo concludes there would be no impact on the effective reducing capacity of the grout, because clean cap grout has a greater weight percent GGBFS than LP#8-016 reducing tank grout (i.e., 45 wt percent per Procurement Specification C-SPP-Z-00012, Revision 1 vs. 30 wt percent per Procurement Specification C-SPP-F-00055, Revision 4. The memo also notes that the clean cap grout volume within the tank would be less than 10 percent of the total tank volume and would be located at the top of the system instead of near the contaminated zone at the floor of the tank. Notably, the memo acknowledged that clean cap grout may not have a compressive strength meeting the minimum threshold of 13,800 kPa (2,000 psi or 138 bars), but argues that the total volume of this grout within the tank is limited and its use will minimize voids, and thereby the memo concludes that the grout material's overall functionality will not be impacted and that the overall stability of Tank 16H will be maintained during the period of concern. The memo also concludes that filling the upper portions of the tank primary and concrete vault with clean cap grout will not impact the ability of the waste tank design elements (e.g., earthen cover and intruder barrier) to serve as inadvertent intruder barriers. Finally, the memo acknowledges that clean cap grout likely will not have the same hydraulic properties assumed in the PA, which in turn may increase the water infiltration rate to the contaminated zone, because its saturated hydraulic conductivity (K_h) is anticipated to be 6.4×10^{-9} cm/s (SRR-CWDA-2014-00011) rather than the 2.1×10^{-9} cm/s assumed in the PA for LP#8-016 reducing tank grout; nevertheless, the memo argues that this higher K_h for less than 10 percent of the straight-line, through-tank flow path would have only a minor impact on the overall flow of water past the contaminated zone, and thereby the system should remain hydraulically similar to the base case PA model.
The memo reports that grossly conservative HTF Goldsim deterministic model runs demonstrated that the impact on 1- and 100-m peak contaminant doses would be minor, although the peaks would occur earlier.

SRR-CWDA-2015-00160. “Evaluation of the Performance Assessment Impact of Using an Alternative Fill Grout in the H-Area Tank Farm. (Interoffice Memorandum to G.C. Arthur from M.H. Layton).” Revision 0. Aiken, South Carolina: Savannah River Remediation, LLC. January 4, 2016. [ADAMS Accession No. ML16131A229)

The scope of this interoffice memorandum was limited to evaluating the impact that changing the grout used in Tank 16H from LP#8-016 reducing tank grout throughout the bulk of the monolith to an upper layer of more flowable clean cap grout would have on the HTF Performance Objectives described in the HTF Performance Assessment. It was concluded that the alternative fill grout of Specification C-SPP-Z-00012 would perform satisfactorily so that tank grout performance objectives are met. The mechanical requirements for grout performance include adequate compressive strength to withstand the overburden load and to discourage intruders through its physical barrier. When compressive strength testing was performed on Z-Area Vault 4 clean cap grout cylinders made with Holcim Grade 100 slag (rather than the Lehigh Grade 120 slag used in Tank 16H), the compressive strength tests indicated strengths of ≥34,474 kPa (≥5,000 psi or 345 bars), meeting the requirement of compressive strength of ≥13,800 kPa (≥2,000 psi or 138 bars). URS test reports 2014-07V1JE4002-0002 and 2014-07V1JE4002-0003 document these test results and are attached to this memorandum. DOE expects that the change from Holcim Grade 100 to Lehigh Grade 120 slag should either improve or have no impact on the compressive strength and intruder barrier capability of the alternative fill grout. The chemical requirements for grout performance include high pH and low E_h. The alternative grout formula exceeds the GGBFS cement content recommended by SRNL (i.e., ≥210 lbs slag per cubic yard of grout or approximately 6 wt% slag per C-SPP-F-00055) to ensure that high reducing capacity is maintained long term. The hydrologic requirements for grout performance include low saturated hydraulic conductivity to minimize the matrix flow of meteoritic water from the tank top to the contamination zone. When hydraulic conductivity testing was performed of three samples of Z-Area Vault 4 clean cap grout made with Holcim Grade 100 slag, the results indicated an average saturated hydraulic conductivity of 2.2×10^{-9} cm/s in contrast to the assumed HTF PA value of 2.1×10^{-9} cm/s; the measured hydraulic conductivities were 2.7×10^{-9}, 2.4×10^{-9} , and 1.5×10^{-9} cm/s, so only one of the three specimens was less permeable than assumed in the HTF PA. DOE expects that the change from Holcim Grade 100 to Lehigh Grade 120 slag should have negligible impact on the hydraulic conductivity of the clean cap grout, and thereby suggests there should be no hydrologic concerns associated with the change in grout formula. The memorandum concludes that use of the alternative fill clean cap grout (meeting the requirements of Specification C-SPP-Z-00012) for tank grouting can be done in compliance with the HTF performance objectives.

SRR-CWDA-2022-00014. Mangold, J.E. “Dataset for [Tank 16 Clean Cap Grout] Tank 12 CLSM [sic] Modeling in GoldSim (Interoffice Memorandum).” Revision 0. Aiken, South Carolina: Savannah River Remediation. February 24, 2022. [ADAMS Accession No. ML23223A112]

This document is a transmittal memo that accompanied GoldSim modeling files provided by DOE to NRC for review based on NRC staff’s request. These GoldSim modeling files simulate flow and transport of key radionuclides from Tank 16H and are focused on evaluating the performance impact of use of an alternative, more flowable, clean cap grout at the top of Tank 16H to facilitate filling of void space after significant mounding beneath tank risers occurred during placement of reducing tank grout. Reducing tank grout is typically placed in the tank primary and annulus to fill void space and provide stability as part of the tank closure process.

Cells and pipes are used in the GoldSim model to simulate transport of radionuclides. Each cell can be linked to neighboring cells with advective and diffusive input and output links. Pipes use an analytical 1D solution to simulate 1D transport; pipes can take inputs from cells or other pipes. The HTF transport model uses cells within the boundaries of the tank concrete and grout and pipes from the output of the tank vault through the vadose and saturated zones to observation points located 1 m and 100 m from the tank farm boundary. Above the waste zone, several sequences of cells extend upward into the reducing tank grout to account for movement of dissolved waste into the grout mass. Below the waste zone, a series of cells account for mixing and transport above and within the basemat, including lateral inflows. The GoldSim model can also consider alternative fast pathways that allow dissolved waste to bypass the basemat, but this option was not exercised for the Tank 16H alternative clean cap grout analysis.

The Tank 16H alternative grout analysis compared a deterministic bounding simulation to the base case simulation to estimate potential consequences from use of the clean cap grout layer at the top of the Tank 16H primary and annulus. The base case uses the anticipated cementitious material degradation history for Tank 16H with the nominal infiltration rate history and does not consider the impact of fast flow pathways that would enable meteoric infiltration water to bypass slow interaction with reducing grout. The bounding case differs from the base case by accelerating the hydraulic degradation of the reducing tank grout and increasing the infiltration rate to the upper bound estimate (the bounding case inflow is 41 percent greater than the base case maximum inflow). The reported peak of the total dose increased by approximately 41 percent at both the 1-m and 100-m boundary for the bounding case (Figures 1 and 2 of SRR-CWDA-2015-00100) and the timing of the peak decreased from approximately 3,800 yrs to approximately 2,000 yrs. Based on Table 3.2-14 of SRR-CWDA-2010-00128, the cumulative infiltration in the base case at 3,800 yrs (the time of the peak dose in the base case) is the same as the cumulative infiltration in the bounding case at 1,950 yrs (the time of the peak dose in the bounding case).

<u>SRR-TCR-2015-00024. Davis, B. “Tank 16 Grouting Lessons Learned (Memo).” Aiken, South Carolina: Savannah River Remediation, LLC. January 27, 2016. [ADAMS Accession No. ML16119A346]</u>

This memo documented lessons learned from Tank 16H grouting operations. Fourteen items were identified in a table in the appendix to the memo, including recommendations to (i) remove diversion valves from the grout slickline, because their use resulted in grout plugging and ineffective cleaning of the slickline; (ii) replace use of decant totes with waste totes during intact cooling-coil grouting processes, because decant tote usage resulted in high hazard potential; (iii) evaluate and test highly flowable clean cap grout to ensure it meets PA requirements so it can be used with confidence, if needed in the future, to complete primary/annulus grouting; (iv) base grout placement sequence/lift height plans on real grout data about set time, specific gravity, etc., instead of on bounding values to potentially provide more placement flexibility; (v) evaluate impact of eliminating the cooling coil grouting process, because it is the highest hazard grouting operation; (vi) develop a management control plan to conduct failed and intact cooling-coil grouting dry runs; (vii) develop a better method to ensure that the grout slickline is lubricated/wetted before grout introduction; (viii) analyze data from Tank 16H grout testing to develop an acceptable, non-zero range for bleed-water production; (ix) plan grouting operations around seasonal weather expectations; (x) develop a method to flush a cooling coil immediately prior to grouting the coil to reduce hazards, use of resources, and setup time. The report also noted that highly flowable clean cap grout could not be placed into Tank 12H without pre-approval from SC DHEC provided to DOE staff.

USQ-HTF-2015-00635. "Use-As-Is Disposition of Non-Conformance Report (NCR) 2015-NCR-15-WHC-0008 'H Tank Farm Grout – Tank 16' (Non-Conformance Tank 16 Grout Test Cylinders Deviation from Requirements of C-SPP-F-00055, Rev. 4 'Furnishing and Delivery of Tank Closure Grout' Technical Review Package)," Revision 0. September 2015. [ADAMS Accession No. ML22056A509]

The attachment provides the basis for the use-as-is disposition of an NCR related to a slight temperature overage of a curing room in which 12 grout cylinder samples were stored prior to compressive strength testing. Temperatures in the curing room rose to 78.5° F for a period of 2 hrs on June 17, 2015, which is 1.5° F warmer than allowable per ASTM C31/C31M-15, "Standard Practice for Making and Curing Concrete Test Specimens in the Field." Some cylinder break tests conducted on June 30 and July 14, 2015, exhibited compressive strengths below the design requirement of 13,800 kPa (2,000 psi or 138 bar), but results were said to be "within the tolerances of the applicable testing standards ASTM C94 and ACI 301…and as such comply with the strength requirement of specification C-SPP-F-00055 (2015-NCR-15-WHC-0008)." The curing temperature and tolerance prescribed are meant to ensure that accurate compressive strength data are obtained from cylinder break tests. Most of the break tests appended to 2015-NCR-15-WHC-0008 indicated that compressive strengths of this reducing tank grout, which was placed into Tank 16H, exceeded the minimum compressive strength design requirement.

USQ-HTF-2015-00686. "Use-As-Is Disposition of Non-Conformance Report (NCR) 2015-NCR-15-WHC-0013 'H Tank Farm Grout – Tank 16' (Non-Conformance Tank 16 Grout Test Cylinders Deviation from Requirements of C-SPP-F-00055, Rev. 4 'Furnishing and Delivery of Tank Closure Grout' Technical Review Package)," Revision 0. October 2015. [ADAMS Accession No. ML22056A510]

The attachment provides the basis for the use-as-is disposition of an NCR related to three instances of slight temperature overages of a curing room in which curing tank grout specimens deviated from the requirement of a maximum temperature no greater than 77° F (ASTM C31/C31M-15; see also 2015-NCR-15-WHC-0013). The three instances of elevated temperatures were:

Instance 1. The temperature of the curing room rose to 79 °F for 5 hours on July 19, 2015 for twenty-eight batch samples.

Instance 2. The temperature of the curing room rose to 79 °F for 9 hours on July 27, 2015 for twenty batch samples.

Instance 3. The temperature of the curing room rose to 78.5 °F for 6 hours on July 28, 2015 for twenty batch samples.

Because the subsequent cylinder break test results verified that the compressive strength of the affected specimens met or exceeded the minimum requirement of 13,800 kilopascals (2,000 psi or 138 bar; C-SPP-F-00055, Revision 4, "Furnishing and Delivery of Tank Closure Grout), the use-as-is disposition of the NCR was found acceptable, as higher storage temperatures would only serve to decrease the compressive strength of the tested specimens, and yet their strength was not adversely impacted.

USQ-HTF-2015-00706. Layton, M. “Supplier Deviation Disposition Request (SDDR) Number 13307 – Deviation from Specification C-SPP-F-00055, Revision 4 (Technical Review Package).” Revision 0. Savannah River Site, South Carolina. October 2015. [ADAMS Accession No. ML20279A789]

This technical review package includes the documents Design Authority Technical Review (DATR), Unreviewed Safety Question (USQS) review, and Consolidated Hazard Analysis Process Screening (CHAPS), along with the USQ-HTF-2015-00706 Attachment, the Unreviewed Waste Management Question (UWMQ) Determination, and a related E-Mail from M. Layton to R. Voegtlen, dated October 22, 2015. The proposed activity, which was reviewed, was the “use-as-is” disposition of SDDR No. 13307 – Deviation from Specification C-SPP-F-00055, Revision 4, which required that tank closure grout have 0.0 percent bleed after 24 hrs. set time. The documentation indicates that “several” batches of grout used to fill Tank 16H had greater than zero bleed water but was not specific about how many batches were affected. The justification for the use-as-is disposition of the non-zero-bleed grout was that the batches which exceeded the zero bleed requirements met all other performance requirements in the specification, and the non-zero-bleed deviation did not invalidate the requirements or compromise the assumptions of or input to the HTF PA.

WO 01324150-64. Fail, J.A. “TK CLOS & REG CN TO PERFORM GROUT PREP/GROUT PLACEMENT TK 16.” Revision 0. August 22, 2014. [ADAMS Accession No. ML16119A351]

This work order provided detailed lists of activities to be performed during grouting of Tank 16H. This work order is for placing grout in Tank 16H in support of tank closure, including operations such as removal of riser cover port plugs, tremie installation into risers and pumping of grout through slickline piping. The order called for six grout placements (i.e., lifts; HTF-SKM-2014-00031, Grout Placement Plan) to be poured through tremies in multiple risers in the primary (3 lifts) and annulus (3 lifts) with a maximum drop height of 5 ft (1.5 m), including their not-to-exceed volumes necessary to fill the primary tank and annulus, and additional placements for each riser and riser cap. The work order included safety precautions and limitations that were to be followed (including radiation control procedures) during grouting and describes personal protective equipment (PPE) used, and for which steps each PPE is used, lists chemicals employed, checklists for steps to be taken before and during the grouting process, and the steps to be taken if deviations are required.

Appendix B

NDAA WIR Monitoring of Tank Grouting Operations: Questions for DOE Related to Tank 12H and Tank 16H

This appendix provides an update to Appendix B of the Revision 0 version of this Technical Review Report Supplement, which was issued in 2020 as ADAMS Accession No. ML20296A550. Additional information and documents were provided by DOE related to Tanks 12H and 16H grouting operations as email attachments or via teleconference discussion. Due to time constraints during the April 28, 2022, teleconference, the NRC was unable to ask some of the remaining Appendix B questions. Review of DOE responses to Appendix B questions and DOE documents concerning grouting of Tanks 12H and 16H have given rise to some additional questions, as well. DOE provided additional information to address the remaining 10 items not discussed in the April 28, 2022, teleconference in SRMC-CWDA-2023-00074 as noted below.

1. **Grout Specifications & Testing:** While the use of high-range water-reducer ADVA 575 has increased to achieve greater flowability, the viscosity modifying admixture (VMA), EXP 958 dosage has not changed, even though VMAs are used to counter-balance the use of high-range water-reducers, which at higher quantities can lead to excessive bleed water segregation. Why has EXP 958 dosage not changed with the increase in ADVA 575? Please provide the quantity or range of ADVA 575 and RECOVER in fluid ounces that were used to batch tank grout for Tank 12H (the 5 accepted and 5 rejected grout batch tickets for Tank 12H provided in SRR-CWDA-2020-00052 were illegible so NRC could not determine the dosages).

   DOE Response: ADVA 575 ranged 320 to 330 oz and RECOVER ranged 50 to 70 oz in Tank 12H.

   TRR update: See Table 1 of this report.

2. **Grout Specifications & Testing:** Tank 12H was grouted with two different types of grout. Lehigh Grade 120 slag cement was used in the mix to grout Tank 12H only starting on the second day and thereafter, but Holcim Grade 100 slag cement was used in the mix poured on the first and early during part of the second day. Please explain the reasoning for using Grade 100 slag in the first 27 batches of tank grout that were placed into Tank 12H on the first and second grouting days. Was there a decision made to use all existing Grade 100 slag, even if it meant using two different types of slag in grout placed into one tank? Did DOE consider it important to use grout comprised of Grade 100 slag in immediate contact with the waste on the floor of Tank 12H? *Please evaluate the differences in hydraulic conductivity between the Grade 100 and Grade 120 slag tank grout and any resulting performance impact*. Consider using remaining untested samples of tank grout for late-term compressive strength testing.

   DOE Response: The batch plant used up the Holcim Grade 100 slag they had remaining before proceeding to mix reducing tank grout with the new slag. There are no remaining, untested samples of tank grout with which to conduct late-term compressive strength testing.

   Unanswered Question: Please evaluate the differences in hydraulic conductivity between the Grade 100 and Grade 120 slag reducing tank grouts and any resulting performance impact.

3. **Grout Specifications & Testing:** Please clarify if all testing of Lehigh Grade 120 slag is described in VSL-15R3740-1. DOE indicated that additional testing information is provided in SRR-CWDA-2015-00088 but testing results do not appear to be included in this document. What testing, if any, has been completed for tank fill, equipment, cooling coil, and clean cap grout prepared with Grade 120 slag? Has DOE evaluated other reducing tank-closure grouts such as equipment, cooling coil, and clean cap grout? Is there a document available that includes information about Grade 120 slag tank grout wet chemistry test, flow test, compressive strength, and bleed? [Requested References for May 2016 Teleconference (Question transmitted to DOE in March 2016)]

   DOE Response: DOE indicated that there are no other test reports available for Lehigh Grade 120 slag reducing tank grout.

4. **Grout Specifications & Testing:** NRC requested the final specification for clean cap grout as a follow-up action to the May 17, 2016, teleconference. Could DOE clarify how it achieves the minimum flowability given that SRNL-STI-2012-00558 indicates that flowability would be compromised at a water-to-cement ratio of 0.51, and that the one most-relevant sample tested in SRNL-STI-2012-00558 (sample WP023 with a water-to-cement ratio of 0.51) had slump flow of only 18.6 cm (7.5 in) and no sample had greater slump flow than 29 cm (11 in)? Could DOE clarify if any Daratard or any admixtures were used in the Tank 16H clean cap specification, or if there is an option to use admixtures in the future?

   Because this question was not discussed, this was Follow-Up Action Item No. 1: NRC staff recently reviewed the procurement specification for Vault 4 Clean Cap Grout (C-SPP-Z-00012). The specification presented three alternatives for clean cap grout but did not indicate which was selected for use in Vault 4. All three potential Vault 4 mix designs called for ASTM C1611 slump flow to be in the range of 66–97 cm (26–38 in), but an apparently relevant test sample of saltstone, WP023 having w:c = 0.51, had a slump flow of only 18.6 cm (7.5 in) and no sample had slump flow greater than 28.3 cm (11.1 in) (SRNL-STI-2012-00558). Which, if any, of the three alternatives presented in C-SPP-Z-00012 was placed into Tank 16H to complete its bulk fill? What was the w:c ratio of Tank 16H clean cap grout? Was the Tank 16H clean cap grout formula mixed with water or with a caustic aqueous solution of NaOH? Please provide the measured slump flow values for the batches of clean cap grout placed into Tank 16H. Please indicate if any admixtures were used in the production of Tank 16H clean cap grout to enhance flowability or prevent bleed-water segregation.

   DOE responded in SRMC-CWDA-2023-00074: Vault 4 Clean Cap 1 as defined in C-SPP-Z-00012 was used to complete Tank 16 bulk fill. The w:c ratio for this mix is 0.5. Water was used for the mixture, not a caustic aqueous solution of NaOH. Three slump flow values were obtained for the clean cap grout formula during bulk fill for Tank 16: 31.5” at 85°F, 32.5” at 88°F, and 36” at 89°F, all within the acceptable range of 26-38” as listed in C-SPP-Z-00012. No admixtures were used in the Tank 16 clean cap grout, and the specification does not explicitly list an option to do so. As noted above, all clean cap grout batches passed the slump flow test in the field at the time of use. VSL-14R3330-1 (NRC Accession No. ML20279A790) looked at the effect of decreasing w/pm ratio on flowability in clean cap grout and showed that a w/pm ratio of 0.5 did not significantly reduce slump flow. It should also be noted when comparing these studies that differing test methods were used. SRNL-STI-2012-00558 uses ASTM D6103 which is the test method for Controlled Low Strength Materials (CLSM), while VSL-14R3330-1 uses ASTM C1611 and a mini slump flow method. ASTM D6103 uses a cylinder with a height of 6” and a diameter of 3”, while ASTM C1611 uses a cone with a top internal diameter of 4”, a bottom internal diameter of 8”, and a height of 12”. The mini slump test used a cone with a top internal diameter of 2”, a bottom internal diameter of 4”, and a height of 6”. The difference in size for these containers would change the volume of grout used for the test and therefore the spread. SRNL-STI-2012-010558 values would be lower than that listed in the specification since the specification relies on the larger cone volume used in ASTM C1611.

5. **Grout Specifications & Testing:** With respect to SDDR No. 13307, the document has two attachments documenting the two highest bleed results, which were 8.9 percent (June 18, 2015) and 3.3 percent (June 19, 2015), but the deviation description states that none of the bleed tests resulted in zero bleed. Please indicate if this statement was true over a limited time-range, or for every batch placed into Tank 16H. On page 4 of the SDDR, DOE states that bleed test results varied from 0.0 to 8.9%, which isn’t consistent with page 1 that states none of the bleed tests resulted in 0.0 bleed—please explain. DOE also stated that the initial grout mix qualification test results for these two batch tickets show that these batches met the zero-bleed requirement (initially, but not after 24 hours). Please clarify.

   Because this question was not discussed, this was Follow-Up Action Item No. 2.

   DOE responded in SRMC-CWDA-2023-00074: The statement in the deviation description on page 1 of the SDDR is not correct for all samples taken during grouting operations. The statement that bleed test results varied from 0.0 to 8.9% on page 4 of the SDDR is correct. For all the Tank 16 field tests performed during grouting operations, 37 of 54 samples showed zero bleed at 24 hours and the average was 0.7%. The zero bleed requirement made in the specification (C-SPP-F-00055, Section 3.2.1.2.A.6) is for trial batching to be performed before grouting begins to show the mix is capable of achieving zero bleed after 24 hours. This requirement was met as documented in the trial batch report contained on page 19 of the SDDR.

6. **Grout Placement:** NRC reviewed DOE's Tank 16H grouting operations lessons learned document (SRR-TCR-2015-00024), which included the recommendation to devise grout placement sequence/lift height plans on real grout data for set-up time, specific gravity, etc., instead of on bounding values, to potentially provide more placement flexibility. Please indicate whether the Tank 12H lift height analysis was based on bounding values or realistic values, and if based on bounding values, will realistic values be used for Tank 15?

   Because this question was not discussed, this was Follow-Up Action Item No. 3.

   DOE responded in SRMC-CWDA-2023-00074: After establishing the preferred lift heights for Tank 12 grout placement, the Tank 12 Project Team determined the planned Tank 12 lift heights were within the bounding limits calculated to support Tank 16 grouting operations, and therefore did not rework calculations to utilize actual values. There have been no decisions made for lift height analysis in Tank 15, therefore, whether bounding or actual values will be used has not been determined.

7. **Grout Transferability, Flowability & Mounding:** DOE estimated that 3,003 cubic meters (3,928 cubic yards) of grout would be required to fill a generic, empty Type I tank (U-CLC-G-00001), excluding riser volumes. For Tank 12H specifically, DOE estimated that the actual volume of the tank was 3,010 cubic meters (3,937 cubic yards), and that the volume of residual material remaining on the floor of the primary (**Figure 1**) and on cooling coils (**Figure 2**) totaled 7.2 cubic meters (9.4 cubic yards) (SRR-LWE-2016-00036; U-ESR-H-00125; M-CLC-H-03256). Accounting for the residual material volume, the final estimated Tank 12H grout volume (excluding risers) was 3,003 cubic meters (3,928 cubic yards). Please indicate what accounts for the difference between the generic Type I tank and actual Tank 12H volume estimates. Please provide an estimate of uncertainty for these volumes. Please confirm that DOE calculates grout volumes in advance of grouting so that the values provided are not biased.

   NRC is satisfied with available information although this question was not discussed.

8. **Grout Transferability, Flowability & Mounding:** Actual grout volumes placed were calculated based upon the number of mixer trucks that delivered grout to the tank and the assumption that mixer trucks each contained and fully discharged 6.1 cubic meters (8 cubic yards) of grout (SRR-CWDA-2016-00068). Data provided by DOE suggests, however, that mixer trucks may discharge only ~6.0 cubic meters (~7.9 cubic yards) of grout, in practice. Please provide information about the volumetric capacity of the grout trucks and about any limitations on the amount of grout mixer trucks can reasonably discharge. Does the batch plant meter "exactly" 6.1 cubic meters (8 cubic yards) (with what uncertainty) into each truck? When a truck has fully discharged its load of grout, is there an amount of residue remaining on the interior of the truck, such that only approximately 6.0 cubic meters (7.9 cubic yards) are discharged per truck? Is it feasible for each grout truck to deliver its 6.1 cubic meters (8 cubic yards) of grout?

   Because this question was not discussed, this was Follow-Up Action Item No. 4.

   DOE responded in SRMC-CWDA-2023-00074: The batch plant does not measure the exact volume of grout in a truck. The grout specification provides the weight or volume of individual components that make up the grout, on a cubic yard basis, and the batch plant adds the quantity necessary for eight cubic yards. When placing the grout into a waste tank, flow meters are not utilized to determine the volume placed, volumes are estimated based on the assumption that on average each truck contains eight cubic yards of grout. When providing the estimated total volume of grout added to a tank, it is assumed that each truck contains eight cubic yards of grout upon arrival, however, to determine the volume added to the waste tank, any grout discharged to support required receipt testing is subtracted from the eight cubic yards. For example, the information provided which led to the 7.9 cubic yards per truck value calculated by the NRC above, was based on 27 trucks arriving and 213 cubic yards being placed into the tank. However, the 213 cubic yards being placed into the tank accounted for three receipt tests performed during delivery of the 27 trucks. As required in Note 1 of Attachment 5.3 of C-SPP-F-00055, at least 0.8 cubic yards must be dispatched before testing. For the trucks requiring testing, this material was dispatched to a skid pan and not placed in the waste tank and then material was discharged for testing. For estimating purposes, it is assumed that one cubic yard is dispatched for testing purposes, and not placed in the waste tank, each time a test is performed. Therefore, the 213 cubic yards placed into the waste tank accounted for three cubic yards being diverted for testing purposes. While the number of grout trucks emptied, accounting for grout dispatched for testing, is used to estimate the volume of grout placed in a tank, tanks are not grouted until a volume estimate is met. Tanks are grouted under continuous visual inspection until full, with monitoring for potential void spaces occurring throughout the process. The calculated tank volumes and estimated grout placement volumes are used to support the visual verification that no appreciable void volumes remain within a grouted waste tank.

9. **Grout Transferability, Flowability & Mounding:** The Tank 16H lessons learned document (SRR-TCR-2015-00024) addressed needs to (i) remove diversion valves from the grout slickline, because such use resulted in grout plugging and ineffective cleaning of the slickline, and (ii) develop a better method to ensure that the grout slickline is fully wetted/lubricated prior to grout introduction to minimize grout plugging (SRR-TCR-2015-00024). *Please provide insight into whether this lesson learned represents a long-term issue that DOE has been tracking through multiple tank grouting operations.*

   DOE Response: DOE will not use the diversion valves for grout slick lines in the future.

   Unanswered Question: Please provide insight into whether this lesson learned represents *a long-term issue that DOE has been tracking through multiple tank grouting operations.*

   This unanswered question was Follow-Up Action Item No. 5.

   DOE responded in SRMC-CWDA-2023-00074: Diversion valves were not used for other tank grouting operations prior to Tank 16 grouting. Tanks 18 and 19 used a slick line that went directly to a single-entry point in the tank. Tanks 5 and 6 used line segments with spool pieces to divert to different fill locations. The grout plugging due to diversion valve use was therefore not observed in any previous grouting operations prior to Tank 16 grouting and was not a long-term issue. Based on lessons learned from Tank 16, Tank 12 grouting did not utilize diversion valves.

10. **Grout Transferability, Flowability & Mounding:** The Tank 16H grout strategy indicated that having 8 to 10 cement mixer trucks in rotation was ideal (SRR-LWE-2014-00013), whereas the Tank 12H grout strategy later clarified that a grout delivery rate of 8 to 10 trucks per hour (SRR-LWE-2014-00147) was ideal. Which of these two statements is correct?

    DOE Response: A truck takes about an hour per rotation, so both statements are correct (8–10 cement trucks in rotation is ideal, and 8–10 trucks per hour is ideal).

11. **Grout Transferability, Flowability & Mounding:** Has DOE made an effort to establish a causative relationship or correlate ambient temperatures or grout placement rates with the Tank 16H mounding phenomenon (ADAMS Accession No. ML16167A237), which, if undertaken, would improve understanding of contributing factors or has DOE taken steps to study this phenomenon in the future? For example, DOE could monitor in-tank temperatures (ADAMS Accession No. ML16167A237), which are expected to be dominated by the heat of hydration during grouting operations. While the tanks are located underground and are insulated from surface temperature fluctuations, DOE indicates that ventilation of the tanks introduces ambient air into the tanks and could influence in-tank temperatures during grout hydration.

    DOE Response: DOE has no plans to monitor in-tank temperatures.

    Unanswered Question: Has DOE made an effort to establish a causative relationship or correlate ambient temperatures or grout placement rates with the Tank 16H mounding phenomenon (ADAMS Accession No. ML16167A237), which, if undertaken, would improve understanding of contributing factors to excessive grout mounding? Has DOE taken steps to study this phenomenon in the future?

    NRC interpretation: DOE has no current plans to study the reasons for excessive grout mounding during placement of reducing tank grout into Tank 16H.

12. **Bleed Water Segregation:** Residual pools of flush water present on the floor of Tank 12H before grouting began were mapped by DOE contractors so that those areas could be purposefully avoided during initial grouting of Tank 12H (ADAMS Accession No. ML16111B174). Does DOE have such maps or further information available about where residual water remained in the tank for NRC review? DOE should provide additional information regarding the quantity and performance impact of the standing water that was present in Tank 12H during grouting.

    DOE Response: The standing water in Tank 12H at the start of grouting was left over from waste retrieval operations. **DOE will check if they can provide maps of standing water at the start of grouting to NRC.**

    Additional NRC request during teleconference: Please indicate how DOE contractors grouted around the pools of water. Please indicate any potential impacts associated with grouting adjacent standing water. **DOE will follow-up with additional information on this question.**

    These unanswered requests/questions were Follow-Up Action Item No. 6.

    DOE responded in SRMC-CWDA-2023-00074: Attachment 2 provides a map of the standing water about one week prior to the initiation of grouting. The depth of any standing water was not provided. A map made in October 2014, prior to sampling (U-ESR-H-00125, Attachment O), noted 1.5” of water below Riser 1 and 2.0” to 2.5” below Riser 5. The map provided as Attachment 1 of this document shows the area under Riser 1 was dry when grouting of Tank 12 was initiated in Riser 1 on 1/19/2016. On 1/19/2016, a total of 20 trucks were discharged into Riser 1. The plan for the second day of grouting was to discharge into Riser 5. A visual inspection of the tank on the morning of 1/20/2016 showed the grout from the first day had made its way under Riser 5 and there was no standing water directly under Riser 5. Testing of the effect of adding grout into standing water has been performed in the past with 4” of standing water, significantly higher than what was seen in Tank 12H. While grouting directly into 4” of standing water caused segregation to occur and increased likelihood that the grout would not meet requirements for compressive strength, ”standing water (in the tank primary or annulus) does not necessarily result in unsatisfactory grout, provided grout placement is controlled in such a manner as to ensure that the excess water does not hamper grout curing or cause excessive segregation.” (SRR-CWDA-2012-00051, NRC ADAMS Accession #ML13078A206) Visualization throughout the grouting process by camera inspection allows for placement of grout in locations with the lowest amount of standing water possible.

13. **Groundwater In-Leakage:** As tank grout placed into Tank 12H primary approached the tank roof and risers, liquid perched on the grout surface was observed from several of the risers (SRR-CWDA-2016-00068; SRR-LWE-2016-00036). Has DOE considered that the rising liquid level could have been comprised, in part, of bleed water that segregated from grout flow lobes, flowing to low areas near the tank wall? Tank grout comprised of Grade 120 slag may produce more bleed water than tank grout comprised of Grade 100 slag (VSL-15R3740-1). NRC recalls a water/liquid removal procedure being in place for Tanks 5F and 6F, but that it was not implemented for those tanks. When rising liquid levels were observed approaching the roof of Tank 5 or 6 [perhaps a 0.3-m (1-ft)-thick layer of liquid], why was it unnecessary to pump out the excess (follow-up question from discussion during August 2018 OOV)? Was dry grout mix added to absorb the liquid, as mentioned in a recent work order? Is Tank 12H the first tank for which water was pumped out late during grouting?

    DOE Response: DOE indicated that the standing aqueous liquid that was pumped out of the risers toward the end of grouting could have also been partly due to bleed-water segregation, in addition to groundwater in-leakage due to a crack in Riser 8, rainwater entering riser openings, and use of slick line lubricant. DOE indicated that no dry grout has been added to any FTF or HTF tank to absorb excess liquid to date. DOE also indicated that Tank 12H was the first for which liquid had to be pumped out of a riser because it was not re-absorbed into the grout prior to the grout reaching the top of the tank.

14. **Groundwater In-Leakage:** During the May 17, 2016, teleconference, DOE indicated that it is working with SCDHEC to enable original, operational ventilation systems to remain in place during future grouting operations (ADAMS Accession No. ML16167A237) to better manage water ingress. Would DOE please provide an update on the status of these discussions and plans?

    DOE Response: DOE was previously required to completely isolate supporting systems prior to grouting. Currently, DOE has increased flexibility with respect to isolation of systems from service. The primary concern is isolation of systems is to ensure that no additional chemicals are added to the tanks (e.g., transfer lines that send waste from the canyons to the high-level waste tanks). But supporting utilities (power, water, ventilation) can now be left in place and used during grouting with isolation occurring later. This flexibility is captured in the Consolidated General Closure Plan (CGCP). Diversion boxes 5/6 are the first structures closed under the newly revised CGCP. This capability will apply to closure of Tank 15H.

15. **Groundwater In-Leakage:** It is NRC’s understanding that DOE stopped work twice during Tank 12H grouting due to groundwater in-leakage into the annulus. First, initial planned grouting of the first annulus lift was delayed due to groundwater ingress and required

pumping of 3,785 L (1,000 gal) of water. Then, water was also observed flowing into the vertical ventilation inlet duct of the Tank 12H annulus (SRR-CWDA-2020-00058) through a crack in the duct wall before the grouting of this ductwork was completed (SRR-CWDA-2016-00068). DOE described that a clay ventilation pipe was a source of groundwater leaking into the annulus (August 2018 OOV). DOE contractors indicated that a vertical leg of the annulus ventilation duct required 1,893 L (500 gal) of groundwater to be pumped out. Did this second event all occur on one day, from discovery to resolution of the issue and completion of ductwork grouting? On what date(s)/during which lifts did this second water ingress and pumping of another 1,893 L (500 gal) of water occur?

DOE Response: The leak was discovered on March 2, 2016. DOE contractors began pumping water out on April 14 and completed this task on April 15, 2016. DOE contractors began grouting the inlet duct within hours on April 15, 2016. The estimated groundwater in-leakage rate was 6 gal/hr.

16. **Groundwater In-Leakage:** Tank 12H is susceptible to groundwater intrusion due to its location below the water table. DOE should provide additional information about the anticipated performance impact on grout in Tank 12H of groundwater saturation. *Will DOE undertake modeling to estimate the rate at which the grout monolith of Tank 12H will wet up due to in-leakage*?

    DOE Response: DOE indicated that the Tank 12H grout monolith is assumed in hydrologic modeling to be fully saturated from the start, and inquired if NRC staff could provide additional information about its information request.

    NRC Response: The NRC staff clarified that the question is in regard to impacts on grout performance and grout quality inside Tank 12H due to it being fully submerged, completely saturated, and subject to groundwater in-leakage (e.g., locally large *w:c* ratios of fresh grout during and after placement due to bleed-water segregation and in-leakage), or to impacts on performance of having a non-homogeneous monolith comprised of grout segments that were placed with variable *w:c* ratios that thereby have different hydraulic properties.

    NRC's contractor, CNWRA, further clarified their interest in quantifying any difference in grout performance for submerged versus unsubmerged tanks due to excess liquid present in submerged tanks during and after grouting.

17. **Annulus & Ventilation Duct Grouting:** The Tank 12H closure module (SRR-CWDA-2014-00086) suggested that a more flowable grout might be used to grout future ventilation ducts, and DOE reiterated the potential use of a more flowable grout for ductwork during the February 2–3, 2016, OOV. The Tank 12H grout strategy document (SRR-LWE-2014-00147) did not address use of a more flowable grout for this purpose (ADAMS Accession No. ML16111B174). Work order WO 01337683-33 indicates that Lifts 5, 7, and 9 partially consisted of placement of cooling coil grout inside the annulus ventilation duct, addressing the issue of grout flowability within the ductwork. It is NRC staff's understanding that this is the first tank for which flowable cooling coil grout was placed into the annulus ventilation duct. Please indicate if DOE had a concern about filling the ductwork using the annulus grout that led to this new use of a more flowable grout. If there was a concern, please provide data or evidence from relevant grouted tanks that supports why this was a concern.

    DOE Response: For Tank 12H, DOE had allowed within the work packages the capability to use more flowable cooling coil grout in the ventilation ducts. The annulus grout lifts for

Tank 12H include Lifts 2, 3, 5, 7, and 9. At the beginning of Lift 5, DOE used 2 supersacks of cooling coil grout to fill a portion of the vertical section of the annulus ductwork. The remainder of Lift 5 used reducing tank grout to fill a portion of the annulus area outside of the ductwork. When water was discovered to be collecting on top of the grout in the annulus ductwork, DOE combined Lifts 7 and 9 into a single lift to fill the remainder of the annulus outside of the duct and then, after removing the water, finished internally grouting the duct. No cooling coil grout was used in Lifts 2, 3, 7 and 9. Lift 5 was approximately one-third of the annulus volume, above the horizontal ductwork. DOE stated that there was no distinct concern that led to use of more flowable cooling coil grout inside the Lift 5 duct work.

18. **Cooling Coil Flushing & Grouting:** Intact cooling coils of Tank 12H were flushed once prior to grouting to remove chromate water, which was sent through a hose to Tank 10H, Riser 3 (SRR-CWDA-2020-00052; WO 01337683-31-A; HTF-SKM-2015-00010). Intact cooling coils remained full of water at the conclusion of flushing (SRR-CWDA-2020-00052). After Lift 8 was complete and the primary had been filled with bulk grout (ML18247A080, Slide 21), flushwater remaining in the coils was flushed again on March 17 and 21, 2016, through hoses into stand-alone, 1135-L (300-gal) gray-water collection totes by grout pumped into the coils (HTF-SKM-2015-00010); this process minimized air entrainment and helped maintain the water-to-grout interface inside the coils (ADAMS Accession No. ML16167A237). Please indicate if chromate flushing into Tank 10 also occurred on these intact coil-grouting dates, or beforehand, and when it occurred.

    DOE Response: On March 16, 2016, flushing of cooling coils into Tank 10 took place. On March 17 and 21 DOE contractors grouted the cooling coils. There are no plans to terminate cooling coil grouting.

19. **Cooling Coil Flushing & Grouting:** The 8 intact cooling coils of Tank 12H were grouted only from the coil inlet (SRR-LWE-2016-00036). When a solid stream of grout was visually detected at the coil outlet, a minimum surplus of 38 L (10 gal) of grout was introduced to the coil to ensure complete filling (ADAMS Accession No. ML15239A612; SRR-CWDA-2015-00159; SRR-LWE-2016-00036; WO 01337683-31-F). Does DOE measure the discharged grout volume to determine if more than 37.9 L (10 gal) was introduced to a coil, or does DOE know the coil capacity ahead of time (coil volume) and add 37.9 L (10 gal) to determine the volume of grout to be injected into the coil?

    DOE Response: DOE will provide a response at a later time.

    This unanswered question was Follow-Up Action Item No. 7.

    DOE responded in SRMC-CWDA-2023-00074: Coil capacity is estimated ahead of time. Grout is added by the full hopper volume, which are increments of 0.75 cubic yards (CY). For example, Coil #30 was estimated to require 109 gallons (0.54CY) of grout. One full hopper was added to the coil, meaning 150 gallons (0.75CY) was pumped into the coil, well above the estimated volume and additional 10-gallon value.

20. **Cooling Coil Flushing & Grouting:** With regard to work order WO 01337683-31-A (Tank 12H coil flushing spreadsheet), please explain the term “water buffalo level” and the disconnect between the water levels recorded before, after, and the volumes required [which do not appear to add up, even with adding a minimum of 37.9 L (10 gal) extra].

DOE Response: DOE will advise what a water buffalo is.

Unanswered Questions: Please explain the disconnect between the water levels recorded before, after, and the volumes required (which do not appear to add up, even with adding a minimum of 37.9 L (10 gal) extra). Please explain the term “water buffalo level.”

These unanswered requests/questions were Follow-Up Action Item No. 8.

DOE responded in SRMC-CWDA-2023-00074: The water buffalo is a 1000-gallon water tank mounted on a trailer that supplies the flush water. Water levels within the water buffalo are measured to the 25-gallon mark. The difference between final and initial water buffalo levels is used to estimate the volume of water passed through the cooling coil with the closest possible 25-gallon increment to the required volume being used. When the volume of water passed through each coil is calculated the only discrepancy with the required volume is Coil #18, which was documented as having 150 gallons flushed through it but the difference in water buffalo level indicates 200 gallons of water were spent. For the first coil of the day an additional 40 gallons of water were used to fill the supply hose, which was Coil #18. This accounts for the inconsistency between the flush volume and the water buffalo difference value.

21. **Cooling Coil Flushing & Grouting:** With regard to work order WO 01337683-31-F (Coil Grout Spreadsheet), please explain why this spreadsheet addresses only 5 of 8 intact coils, and why the coil capacity noted here differs from the required flush volumes per coil (WO 01337683-31-A).

DOE Response: There was a missing second page that the DOE will send to the NRC.

Provision of the missing second page was Follow-Up Action Item No. 9.

DOE responded in SRMC-CWDA-2023-00074: DOE provided the second page of WO 01337683-31, Attachment F, which contained the cooling coil capacity of 3 of 8 coils.

22. **Riser Grouting:** It was pre-estimated that 34 cubic meters (45 cubic yards) of tank grout would be required to fill the risers, including four spray chambers (SRR-LWE-2016-00036). However, only approximately 20 cubic meters (26 cubic yards) of tank grout were used to fill the risers and spray chambers and this is consistent with the grouting operation work order's description of the estimated riser fill volumes, which total 20 cubic meters (26.2 cubic yards) (WO 01337683-33). *Please explain how the total riser volume in SRR-LWE-2016-00036 was mis-estimated, when the total riser volume was accurately estimated in the WO.*

    DOE Response: The riser volume in SRR-LWE-2016-00036 was mis-estimated.

    NRC is satisfied with available information (see Table 3 in Revision 1 of this TRR) although the question was not answered.

23. **Riser Grouting:** During the final stages of riser grouting in the Tank 12H primary, a liquid spill onto the tank top occurred when liquid that had accumulated in the tank primary overtopped a riser. DOE thinks the liquid spill was from a riser that was not being monitored by a camera, but the specific riser that was overtopped was not identified in the lessons learned document (SRR-TCR-2016-00007). Please identify the specific riser involved in this liquid spill, and additional reports or documentation of the incident, as well as any video footage.

    DOE Response: The spill occurred on March 7, 2016. Spray chambers 6–8 ft high were left in place during Tank 12H grouting, making it difficult to observe rising grout levels inside Tank 12H risers. While filling Riser 3, grout backed-up into the Riser 3 spray chamber above tank level. This was recognized when a ball-shaped, pipe-cleaning pig floated up into the riser and was seen floating around at the elevation of the spray chamber flush ring. Riser 7 was not as well-sealed as other risers were and grout exited Riser 7 and spilled onto the top of Tank 12H. DOE contractors contained the spilled grout with spill kits, cleaned-up the grout spill, and capped the area with grout.

    Subsequent NRC inquiry at the teleconference: What was volume of grout that spilled onto the top of Tank 12H?

    DOE Response at the teleconference: The area covered by the spilled grout was approximately 20 sq meters (200 sq ft).

    Follow-Up Action Item No. 10: NRC requests DOE confirm that grout was being placed into Riser 3 when grout leaked around a riser cover port plug at Riser 7. NRC also requests DOE provide illustrations or photographs of typical spray chambers associated with tank risers to better understand how the spray chambers interfere with riser grouting observations. Finally, NRC requests that DOE provide illustrations or photographs of typical riser cover port plugs.

    DOE responded in SRMC-CWDA-2023-00074: DOE provided two computer aided design drawings in response to NRC's request for illustrations of typical spray chambers and riser cover port plugs (see Attachments 3 and 4 in SRMC-CWDA-2023-00074).