TECHNICAL REVIEW OF DOE DOCUMENTATION ON CLOSURE OF ANCILLARY EQUIPMENT AT THE F-TANK FARM FACILITY, SAVANNAH RIVER SITE

Date: September 2023

Technical Reviewers:

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Primary Documents Reviewed:

1. C-DCF-G-00397. "Populate Mix Design Tables, Attachment 5.5" (Design Change Form). November 19, 2015. [ADAMS Accession No. ML21139A044]
2. C-DCF-G-00400. Blankenship, J.K. "Revise 'Designing, Furnishing and Delivery of Ready Mixed Concrete, Grout and CLSM (U)' Specification (Design Change Form)." Revision 0. February 28, 2018. [ADAMS Accession No. ML21139A043]
3. C-SPS-G-00096. Baldwin, G.R. "Designing, Furnishing and Delivery of Ready Mixed Concrete, Grout and CLSM (GS & Procurement Specification)." Revision 3. [ADAMS Accession No. ML21139A041]
4. SRR-CWDA-2020-00011. "Industrial Wastewater Closure Module for F-Area Diversion Boxes 5 and 6, F-Area Tank Farm, Savannah River Site." Revision 0. Aiken, South Carolina: Savannah River Remediation. February 2021. [ADAMS Accession No. ML21181A394]
5. SRR-CWDA-2020-00029. Layton, M. "Inventory Assignment at Closure for FDB-5 and FDB-6." Revision 1. Aiken, South Carolina: Savannah River Remediation. February 23, 2021. [ADAMS Accession No. ML21180A428]
6. SRR-CWDA-2020-00055. "FDB-5 and FDB-6 Special Analysis for the Performance Assessment for the F-Tank Farm at the Savannah River Site." Revision 1. Aiken, South Carolina: Savannah River Remediation. February 2021. [ADAMS Accession No. ML21180A433]
7. SRR-CWDA-2021-00010, Attachment 1: "Technical Justification for Use of Low Slump Concrete and Zero-Bleed CLSM for Operational Closure of F and H Tank Farm Ancillary Structures" in *Request for Approval to Use Alternate Fill Materials for Operational Closure of Tank Farm Ancillary Structures at the Savannah River Site, Aiken, South Carolina [Letter from Kenneth Wells (SRR) to Shawn Clarke (SC DHEC)].* Aiken, South Carolina: Savannah River Remediation. February 3, 2021. [ADAMS Accession No. ML23268A450]

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NRC Technical Review

DOE Office of Environmental Management and Savannah River Mission Completion (SRMC) entombed in concrete two F-Area Tank Farm ancillary structures called diversion boxes—F-Area Diversion Box (FDB)-5 and FDB-6. Figures 1 and 2 show the diversion boxes in preparation, before, and after entombment of FDB-5 and -6 in concrete. Diversion boxes are concrete structures that enable radioactive liquids to be transferred between underground waste-storage tanks in the tank farm. These diversion boxes have not been used for more than 3 decades (Beasley, 2022).

Figure 1 Placement of Concrete Surrounding FDB-6. Image credit: J. Beasley "Savannah River Site Grouts, Closes Liquid Waste Structures in Place," DOE EM Newsletter, Vol. 14, Issue 47, December 6, 2022, see https://content.govdelivery.com/accounts/USDOEOEM/bulletins/33abe59.

Figure 2. Before (top) and After (bottom) Pictures of FDB-5 Entombment in Concrete. Image credit: J. Beasley "Savannah River Site Grouts, Closes Liquid Waste Structures in Place," DOE EM newsletter, Vol. 14, Issue 47, December 6, 2022, see https://content.govdelivery.com/accounts/USDOEOEM/bulletins/33abe59.

This technical review report focuses on DOE documentation related to closure of ancillary equipment at the F-Tank Farm Facility, Savannah River Site, Aiken, South Carolina. Summaries of the primary documents listed above are provided in Appendix A. Technical reviews of the documents listed above are the basis for NRC's evaluation of DOE's closure of ancillary equipment at the F-Tank Farm Facility, discussed next.

This detailed review follows an evaluation NRC staff performed on this topic (ML21347A015) at the request of the State of South Carolina's Department of Health and Environmental Control

(SC DHEC). SC DHEC approved DOE's alternative grout request found in SRR-CWDA-2021-00010 (ML23268A450) in a letter dated February 25, 2021 (ML23268A452), and DOE's Industrial Wastewater Closure Plan for FDB-5 and FDB-6 by letter dated June 17, 2021 (ML23268A451).

Summary and Evaluation of Inventory and Final Risk Estimates and Removal to the Maximum Extent Practical of FDB-5 and FDB-6:

Description and Configuration of Diversion Boxes

DOE assumes that pump pits, catch tanks, diversion boxes, and valve boxes contain no significant contamination and therefore, no inventory was estimated for these components in the FTF Performance Assessment (PA) (SRS-REG-2007-00002, Rev. 1). Diversion boxes are shielded, reinforced concrete structures that contain wall-mounted transfer-line nozzles. Transfer lines can be interconnected by installing jumpers between nozzles to complete a desired transfer path, and new transfer paths can be created by switching jumpers inside the diversion boxes, rather than by constructing new transfer lines. Jumpers are stainless-steel pipe segments with special end connections called Hanford connectors to seal against the diversion box wall nozzles. A Hanford connector is a clamp with a gasketed seal affixed to each end of the jumper. Hanford connectors can be tightened remotely using an impact wrench suspended from a crane causing the jaws of the clamp to close and to help seat the gasket securely onto the wall nozzle to prevent leakage during waste transfers. Any leakage from a jumper connection would be contained inside the diversion box and collected into a floor sump with leak detection. The sumps can be drained into a pump pit and transferred to a waste tank (SRR-CWDA-2020-00011). Pump pits are located at low points in the transfer-line system and contain pump tank and hydraulic pumps and/or jet pumps to transfer wastes and facilitate transfer-line water flushes. Most diversion boxes are below ground and lined with stainless steel or sealed with water-proofing compounds and are also accessible for cleaning at the time of closure (SRR-CWDA-2010-00023, Revision 6).

FDB-5 and -6 were built in the mid-to-late 1970s to transfer waste from the 242-3F condensate transfer system (CTS) to Tanks 25F through Tanks 28F, 33F, and 34F (FDB-5); and transfer waste from Tanks 26F and 7F to the 242-1F evaporator (FDB-6). Transfers were only supernate from the tanks or concentrated evaporator discharge back to the tanks; no fresh canyon waste or sludge slurry were sent through the diversion boxes. A description of FDB-5 from SRR-CWDA-2020-00011 is provided below. FDB-6 is similar in construction to FDB-5 and so details regarding FDB-6 are not provided unless FDB-6 specifications are significantly different from FDB-5. The diversion boxes are rectangular concrete structures (e.g., FDB-5 is about 3.9 m (13 ft) long, 3.3 m (11 ft) wide, and 5.1 m (17 ft) high[2] with 0.75-m (2.5-ft)-thick walls and a base slab that is 1.5 m (5 ft) thick. The vaults extend approximately 1.2 m (4 ft) above grade and are covered with three 0.9-m (3-ft)-thick interlocking concrete cell covers that are oriented east to west[3]. A west-to-east sloping[4] sheet metal rain cover is placed over the FDB-5 vault top. I-beams on the underside of the cover create a gap between the top of the cell covers and the underside of the rain cover.

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[2] FDB-6 is a little larger than FDB-5; FDB-6 is 4.5 m (15 ft) long, 3.3 m (11 ft) wide, and 5.4 m (18 ft) high.
[3] FDB-6 has five cell covers oriented north to south.
[4] The FDB-6 sheet metal rain cover is oriented north to south.

The FDB-5 and -6 vault walls and floor are lined with welded, stainless-steel sheets that are approximately 0.3 cm (0.125 in) thick for the wall and 0.95 cm (0.375 in) for the floor and sump floor (SRR-CWDA-2020-00011). The vault floor slopes towards a gutter along the east wall that drains to a stainless-steel lined sump in the northeast corner[5] that is 0.9 m (3-ft long), 0.6 m (2-ft) wide, and 0.48 m (1.6 ft) deep. Sump drainage is controlled by a plug on the end of a fixed rod actuated through a 10 cm (5-in) riser in the cell cover, allowing the sump to be gravity drained to F-Area Pump Pit (FPP)-2 (for FDB-5) and FPP-3 (for FDB-6). A system of leak detection slots exists in the concrete floor underneath the stainless-steel vault floor liner, which are connected to the leak detection box located outside of the northeast corner of the vault[6]. A flush water valve box located at the northeast vault corner at grade level is used to activate a spray-water nozzle system to rinse the diversion box interior if needed. The valve box is 0.9 m (3 ft) long, 0.45 m (1.5 ft) wide, and 0.81 m (2.7 ft) deep with a 0.3-m (1-ft)-thick concrete cover[7]. The flush water piping entered the vault through a 20-cm (8-in)-wide by 25-cm (10-in)-high open slot on the north wall approximately 3.9 m (13 ft) above the vault floor. There was also a HEPA ventilation system at grade level on the east side of the vault. Figures 3 and 4 (top) illustrate many of the features described above on FDB-5.

There are 10 nozzles in FDB-5 with two on each side except for the west side, which has four spare nozzles (i.e., Nozzles 5, 6, 7, and 8 that were installed for future transfer-line connections and were blanked off using dummy Hanford connectors; SRR-CWDA-2020-00011). There were eight nozzles in FDB-6 (four on the south side and two each on the west and east sides). Spare wall Nozzles 7 and 8 on the in FDB-6 were installed for future transfer-line connections and were blanked off using dummy Hanford connectors. Metal pedestals on the vault floor supported the installed jumpers in FDB-5 and -6 (see Figure 3). One other main difference between FDB-5 and FDB-6 is that FDB-6 has 4 access risers as depicted on Figures 4 and 5. Additionally, cracking of the asphalt surrounding FDB-6 along with a process air-line failure indicated poor soil compaction around the FDB-6 vault, confirmed through testing. From September 15 to October 17, 1981, the soil surrounding FDB-6 was excavated and then returned with controlled compaction.

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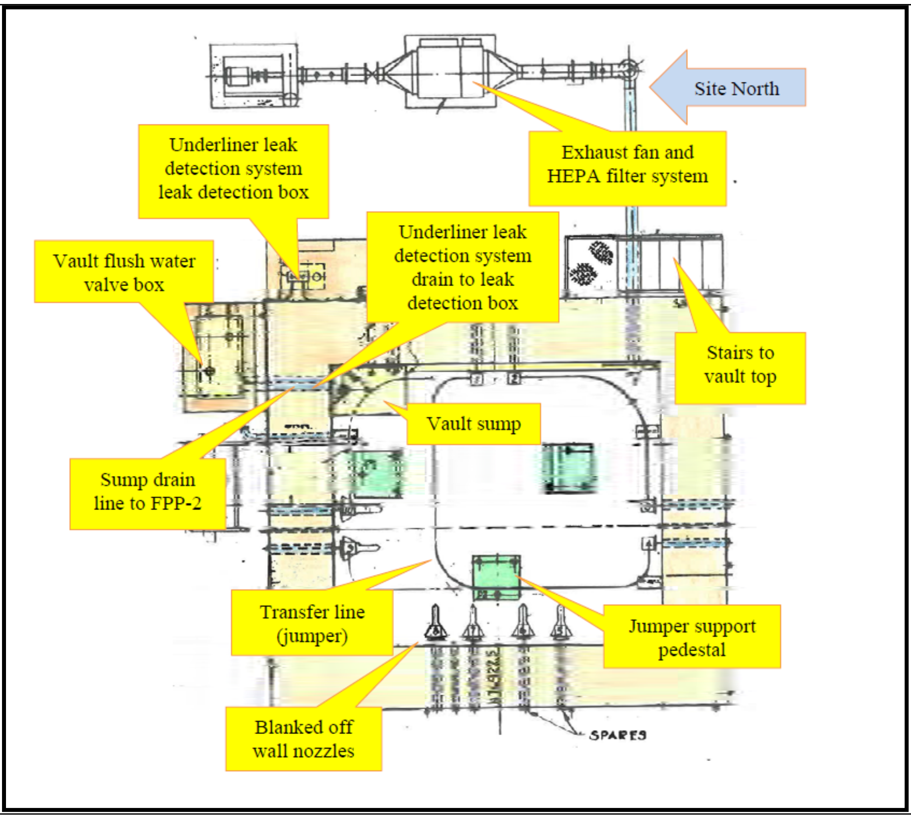
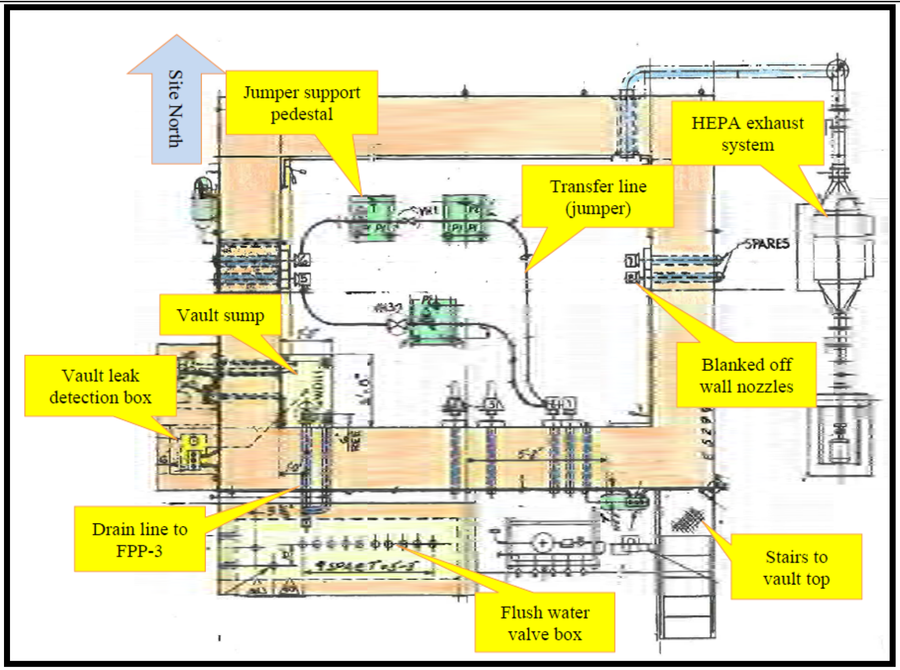
[5] The FDB-6 slump is located in the southwest corner of the vault.

[6] The FDB-6 valve box is located on the southwest corner.

[7] The FDB-6 valve box is larger than the FDB-5 valve box; it is 2.7 m (9 ft) long, 0.75 m (2.5 ft) wide, and 0.9 m (2.9 ft) high.



FDB-5



FDB-6

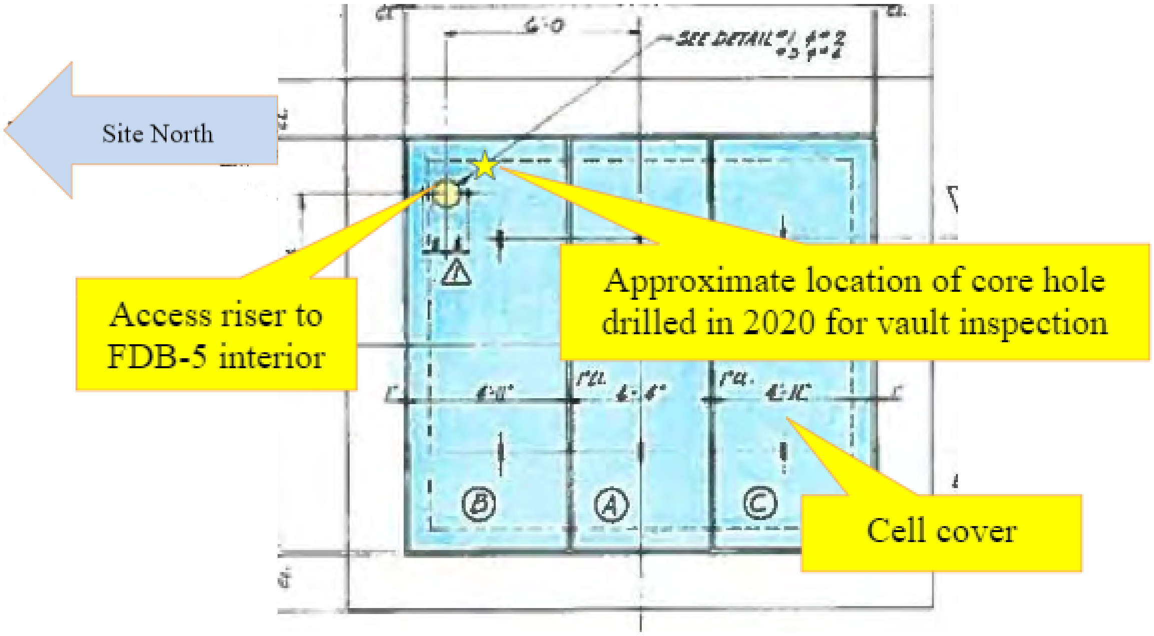
Figure 3. Plan View Maps Showing FDB-5 and -6 Features. Image Credit: SRR-CWDA-2020-00011, Figures 2.1-1 and 2.5-1.

Radiological Status and Inspection of Diversion Boxes

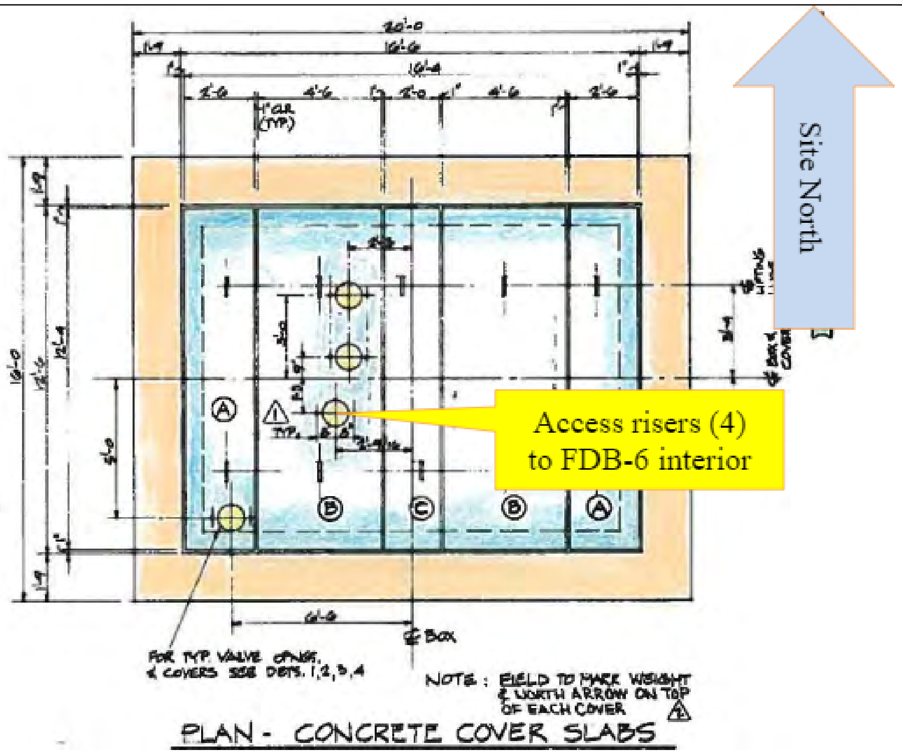
Historical plugging of the FDB-5 jumpers with concentrated, high-salt CTS waste crystallizing inside the transfer lines occurred during cold weather (SRR-CWDA-2020-00011). When a line became plugged, the jumper was disconnected, and a polyethylene tube fed with water was inserted into the line to dissolve the soluble salt waste from the line. Afterwards, the diversion box walls and floor would be washed using the jumper-flushing apparatus. The waste and wash water would collect in the diversion box sump and would then gravity drain to FPP-2. Other than the jumper cleanings, DOE indicated that no other known waste leakage or spillage events are known to have occurred. During video-camera inspection of the FDB-5 vault interior, which was conducted on November 1, 2018, no visible solids were seen on the box floor, while white staining was observed on the walls. This stain was thought to be associated with rainwater intrusion around the sides of the cell covers prior to installation of the rain cover (Figure 6). A relatively small lipstick camera was used in the inspection, because the access riser was partially obstructed with the sump drain plug actuating rod. On February 5, 2020, a second inspection was conducted. This inspection was facilitated by coring a 15-cm (6-in)-diameter hole through the cell cover at a location 81 cm (32 in) southeast of the 13 cm (5 in) access riser on the northeast end of the diversion box to facilitate vault interior inspection (Figure 4, top). In the second inspection, a wider vault area was inspected using a larger camera. This second inspection confirmed the jumper and wall nozzle status and that there was no obvious solid waste on the cell walls and floor (see Figure 7). During a smear survey, the sump screen became dislodged and came to rest on the sump floor. The inspection also revealed that two of the jumpers were abandoned on the floor of FDB-5 (Figure 6). Radiation monitoring using portable, direct reading, ion chamber survey instruments during the coring and inspection measured a 0.01 mSv/hr (1 mrem/hr) extremity dose over the open core hole (TKFM-M-20200205-28).

Previous hydrotesting from FDB-6 to the 242-1F evaporator revealed contaminated water in the sump. Smear samples were taken from the walls of FDB-6. The source appeared to be leakage from a dummy Hanford connector inside the vault. The vault was decontaminated and the area was resurveyed (DPSP 79-21-3). Additionally, in December 1979, 25 cm (10 in) of water were drained from the FDB-6 sump. The source was suspected to be rainwater. The sump level was monitored to determine if water-level increases correlated with tank farm conditions and activities (DPSP 79-21-12).

Three video-camera inspections of FDB-6 were performed with the most thorough inspection occurring on July 13, 2018. Four inspection risers were available on FDB-6 (Figure 4, bottom). A video camera was inserted through the most northerly riser on the vault top. A shiny, black globule of material was noted in the southeast edge of the sump screen, which was hypothesized to be a glue-like mastic used to attach a gasket sealing perimeter space between the vault and the cell covers and on the horizontal interlocking surfaces running the length of the cell covers. A small amount of material that looked like crystallized salt (supernate) was seen on the vault floor near Nozzle 3 and is thought to have come from a leak at Nozzle 4 (U-ESR-F-00092) (See Figure 8). A piece of plastic resembling a “rad bag” (i.e., a plastic bag used to hold potentially contaminated equipment) was also thought to be located beneath a Hanford connector on a disconnected jumper in the northern region of the vault. In total, two discarded jumpers were seen on the vault floor.



FDB-5



FDB-6

Figure 4. Plan View Maps of FDB-5 and FDB-6 Cell Covers. Image Credit: Figures 2.1-1 and 2.5-3 of SRR-CWDA-2020-00011.

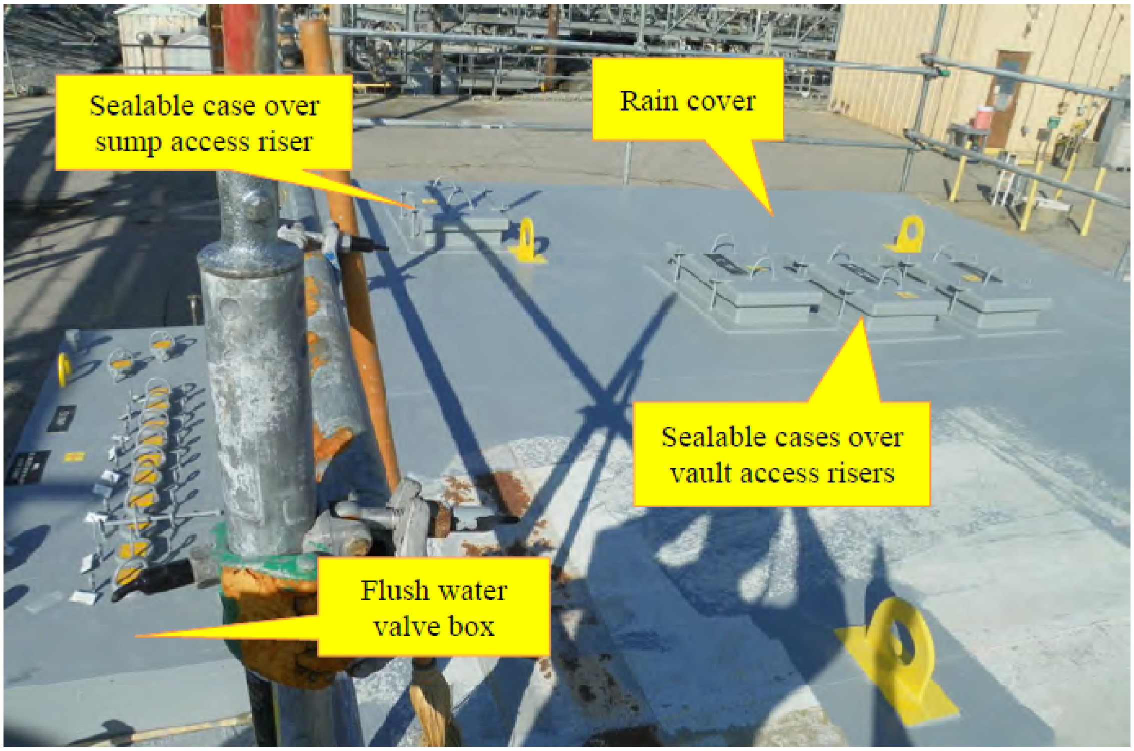


Figure 5. Close Up View of FDB-6. Image Credit: Figure 2.5-5 of SRR-CWDA-2020-00011.

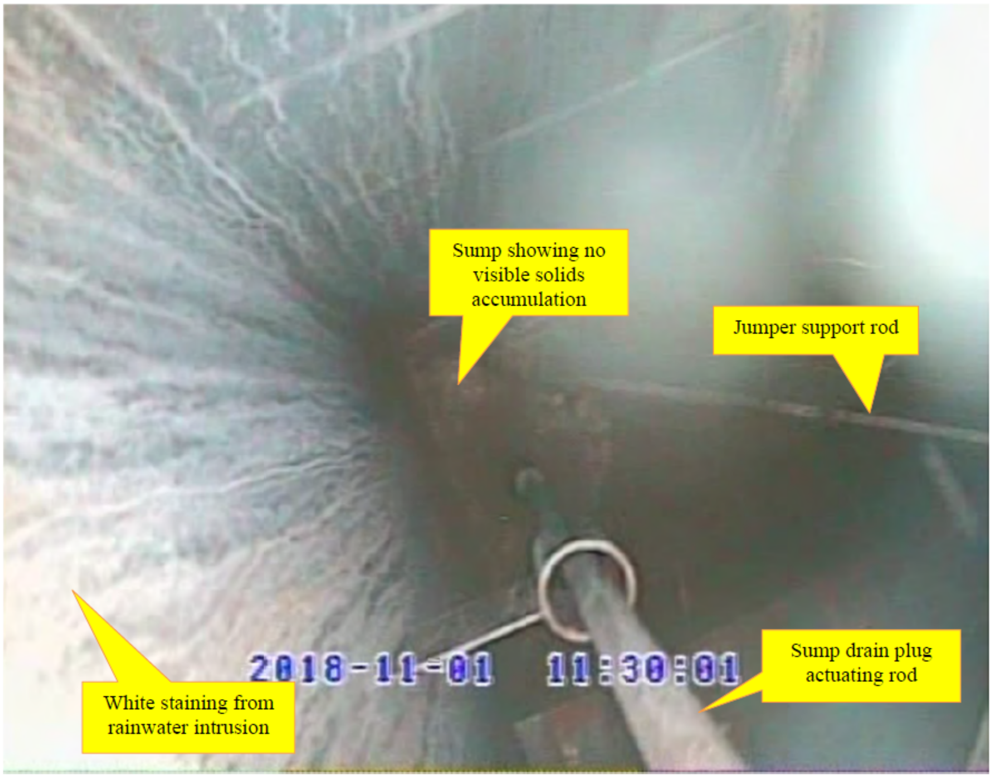


Figure 6. View Looking Down at the FDB-5 Sump (November 2018).
Image Credit: Figure 2.4-1 in SRR-CWDA-2020-00011.

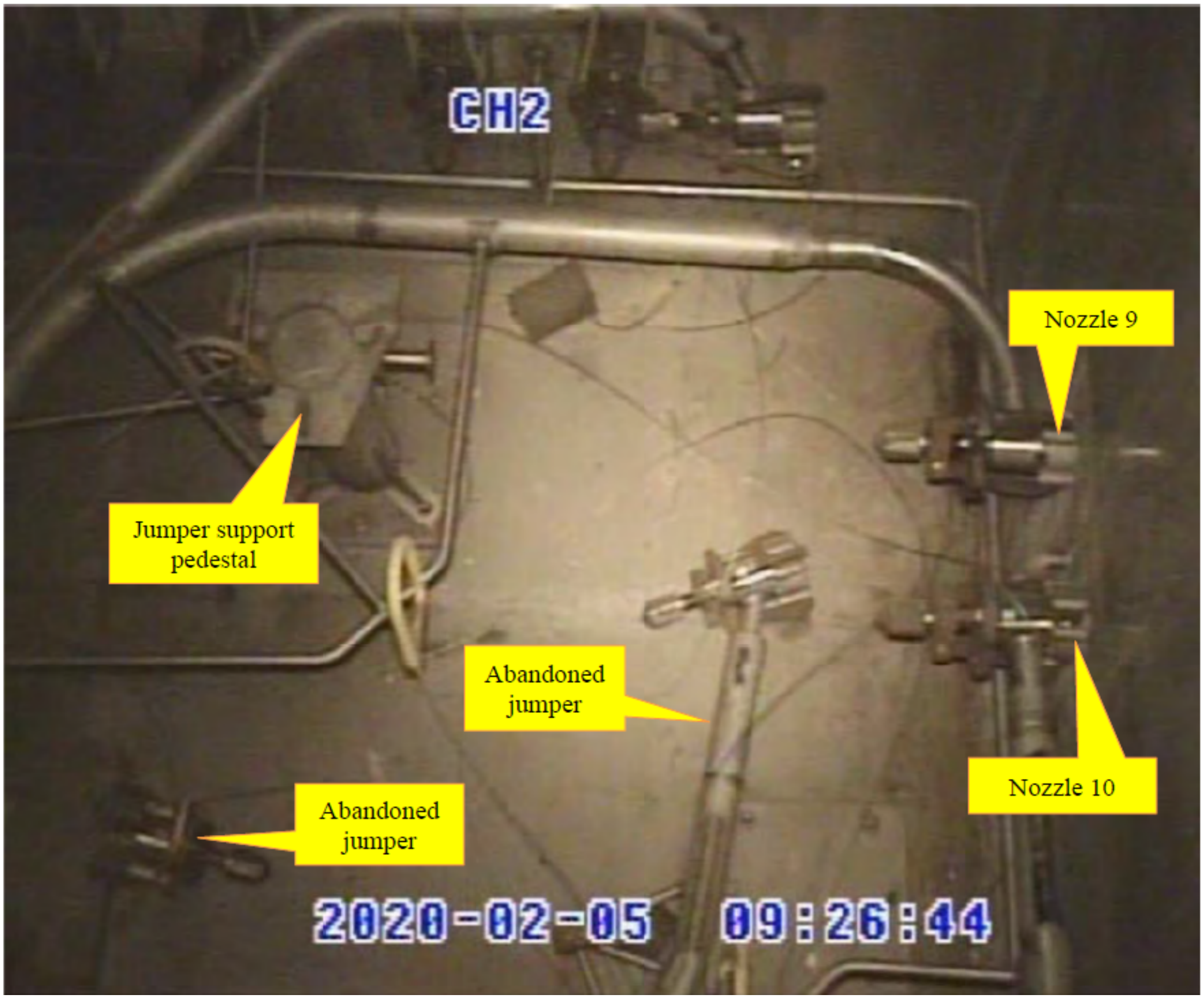


Figure 7. Near-view of FDB-5 Interior During February 5, 2020, Inspection. Image Credit: Figure 2.4-3, SRR-CWDA-2020-00011, Rev. 0.

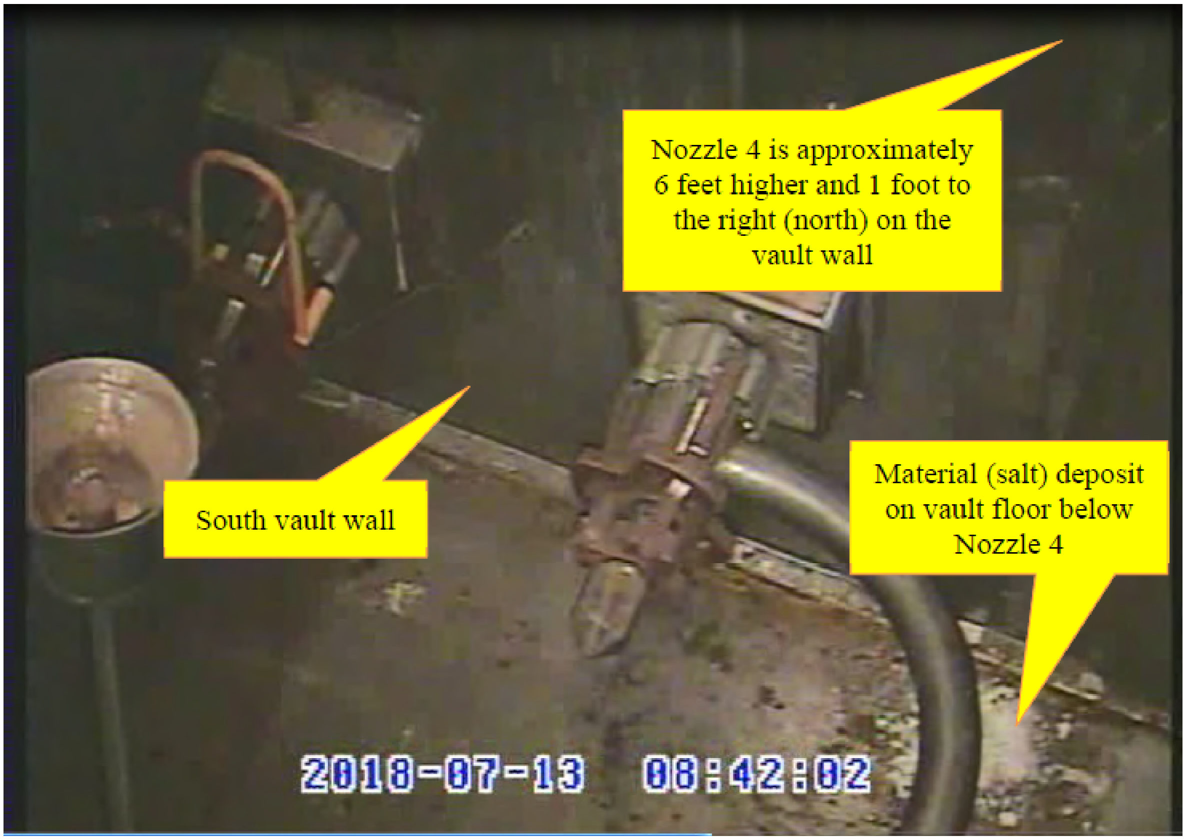


Figure 8. Near-view of a Salt Deposit Below Nozzle 4 in the Southeast Vault Region of FDB-6 During Video Inspection in July 2018. Image Credit: Figure 2.8-3 of SRR-CWDA-2020-00011.

Camera inspections show only a small salt deposit in FDB-6 thought to be associated with a leak due to an inadequate seal between the connector and vault nozzle and no accumulated solids in FDB-5 and FDB-6. The FDB-5 vault could have been contaminated during jumper cleaning, but because the waste is highly soluble salt waste and the vault was washed down after jumper cleaning, DOE reasons that only a minimal amount of residual material may remain on interior vault surfaces and inside the sump drain-line piping. DOE further reasons that because the FDB-5 and FDB-6 transfer lines were typically flushed several times with clean water after each waste transfer, only minimal waste may be present inside jumpers.

Besides the vault washings were associated with jumper cleanings, no additional wash of the FDB-5 vault occurred. FDB-5 was taken out of service September 1985. Following the detection of contaminated water in FDB-6 in March 1979 and the subsequent decontamination[8] of the vault, no additional decontamination occurred in FDB-6. FDB-6 was taken out of service in 1988.

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[8] The decontamination method was unknown but may have just been draining of the contaminated water via the sump to FPP-3. Similarly, the water detected in December 1979 may have just been drained via the sump to FPP-3.

Inventory Development for Diversion Boxes

DOE indicates that trained personnel from SRR Engineering performed a volume determination using the processes described in Tank Mapping Methodology (SRR-LWE-2010-00240) for a small deposit of material on the vault floor below Nozzle 4 and estimated it had a volume of 0.3 gal (1.1 L) with an uncertainty range of 0.1 to 0.6 gal (0.4 to 2.3 L). Other than the small deposit in FDB-6, no accumulated solids were visible upon inspection of FDB-5 and FDB-6 (SRR-CWDA-2020-00011). Any additional remaining residual radioactivity would be difficult to remove or sample and would not justify the characterization effort and cost. The tactic taken by DOE was to estimate a “conservative and bounding” inventory as described in SRR-CWDA-2020-00029 to show the low risk (and low benefit of further removal or characterization) through a special analysis (SA). A proposal to cease waste removal activities in both diversion boxes was submitted on July 13, 2020 (SRR-CWDA-2020-00059). The proposal was based on the inspections and visual evidence showing no significant amount of residual material remaining inside either FDB-5 or FDB-6.

Although no inventory was developed for diversion boxes in the FTF PA, DOE developed an inventory for these FDB-5 and FDB-6 to support the SA, which is found at SRR-CWDA-2020-00055. SRR-CWDA-2011-00050 also commits to characterizing residual materials remaining in a waste tank or ancillary structure being removed from service but has allowances for taking alternative steps (e.g., using process knowledge) to determine an inventory for a waste tank or ancillary structure.

The same approach used in the FTF PA[9] to develop the transfer line inventory was used to develop the inventory for FDB-5 and FDB-6 as described in SRR-CWDA-2020-00029. Transfer lines were assumed to have an inventory associated with three processes:

1. Diffusion into the metal,
2. An oxide film coating, and
3. Residue film remaining after a transfer and flush

The inventory developed in this manner was thought to be appropriate because residual material remaining in the jumpers would accumulate in the same manner as material in the transfer lines. Because the inventory associated with Processes 1 and 2 listed above constitutes less than 1 percent of the total inventory, only Process 3 was considered. Furthermore, while not directly analogous, DOE argues that the approach would also bound the residual radioactivity observed on the floor of FDB-6 during visual inspection. The inventory was determined using information on dry sludge concentration and (i) the estimated surface area of the transfer line interior [assuming a 10-cm (4-in) diameter transfer line and 4 transfer lines or jumpers per diversion box], and (ii) the diversion box floor area (the area calculation neglects the area of the vault and sump walls). The total surface area for 18 and 23 linear m (60.4 and 75 linear feet) of pipe for FDB-5 and FDB-6 respectively, is 16 and 19 m^2 (182 and 209 ft^2).

Representative FTF radionuclide concentrations based on tank concentration and waste transfer data from the Waste Characterization System (WCS) were calculated to determine the FDB-5 and FDB-6 waste inventories for each radionuclide (SRR-CWDA-2020-00011). WCS is an electronic information system that tracks waste-tank data, including projected radionuclide inventories based on sample analysis, process history, composition studies, and theoretical

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[9] See ML112371715 for NRC’s review of the FTF PA including inventory development.

relationships. The same constituents of concern in the FTF PA for ancillary equipment were used for the FDB-5 and FDB-6 inventory development.

WCS is based on dry sludge concentrations and no fresh canyon or sludge slurry waste was sent through FDB-5 and FDB-6; therefore, DOE argues that the concentrations of actinides and long-lived radionuclides are more concentrated in the sludge. DOE stated that shorter-lived radionuclides in the supernate will decay quicker and not be a significant dose contributor for long-term impacts hundred to thousands of years in the future. Still, more soluble waste in the supernate may be underestimated by WCS and some of these radionuclides are expected to be long-lived and relatively mobile (e.g., Tc-99 and I-129). To provide support for the conservatism of the inventory calculations, DOE compares the calculated concentrations of 1506 MBq/ft^2 (4.07×10^{-2} Ci/ft^2) for Sr-90 (the primary beta-gamma source) and 8.9 MBq/ft^2 (2.38×10^{-4} Ci/ft^2) for Pu-238 (the primary alpha source) to actual smear sample results conducted in 2020 of 19 MBq/ft^2 (5×10^{-4} Ci/ft^2) beta-gamma and $9.3 \text{x} 10^{-04}$ MBq/ft^2 (2.5×10^{-8} Ci/ft^2) alpha (SRR-CWDA-2020-00029, Rev. 1), which are orders of magnitude less than the calculated values. Of course, concentrations of more soluble radionuclides that are hard to detect may not be accurately reflected in these comparisons (i.e., smear samples may not capture hard-to-detect radionuclides although these radionuclides may drive dose).

Furthermore, the weighted average concentrations from all waste transfers at the FTF that were reported in the FTF PA (Table 3.3.-11) to calculate the transfer-line inventory were the same concentrations used in the inventory calculation for FDB-5 and FDB-6, although supernate waste from only certain FTF tanks that was sent to and from the FTF evaporators were transferred through FDB-5 and FDB-6. As stated in the monitoring plan, NRC staff expects DOE to validate the assumed inventory for ancillary equipment under MF 1.4 in NRC's monitoring plan. But given the very small volume and inventory of waste potentially present in FDB-5 and FDB-6 compared to other sources at the FTF (i.e., high-level waste tanks), the approach used while limited, is considered reasonable to support the closure of FDB-5 and FDB-6. Opportunities to validate the ancillary equipment inventory at the FTF are expected to occur in the future.

DOE lists several conservative assumptions in inventory development including the following:

- Approximately 0.019 m^3 (5 gal) of material are assumed to remain in FDB-5 and FDB-6, while only an estimate of 0.001 m^3 (0.3 gal) of material was observed on the FDB-6 floor.
- The calculated concentrations are decayed to September 30, 2020, consistent with the PA, while the actual closure date will be further out in time allowing for additional decay.
- Assuming transfers were sludge transfers through FDB-5 and FDB-6 would lead to higher concentrations of transuranic radionuclides of concern.
- The survey results for FDB-5 in 2020 support the conservatism of the calculated inventory.

For the reasons stated above, NRC staff find the inventory developed reasonable and likely conservative for most key radionuclides; however, hard-to-detect and more mobile, long-lived inventories of key radionuclides, such as Tc-99 and I-129, may be underestimated. DOE should attempt to validate the (i) ancillary equipment inventory, and the (ii) calculations and the (iii) model used to estimate the inventories in the future because they are expected to be uncertain (e.g., use of WCS data and continuously stirred tank reactor model with three transfer line flushes to estimate the ancillary equipment inventory).

NRC also recommends that DOE clarify in future documentation the reason for and expected radiological status of abandoned jumpers in the diversion boxes (e.g., clarify whether the jumpers were plugged prior to abandonment, and if so, the degree of flushing and waste dissolution that occurred prior to abandonment of the jumpers in the diversion boxes). NRC staff also recommends that DOE look for opportunities to better validate the method used to estimate volumes of residual radioactivity remaining in the abandoned jumpers that had historically been plugged in future assessments, as conditions warrant.

Special Analysis for Diversion Boxes

FTF PA modeling was updated in the Tank 18/19 SA and the Tank 5/6 SA (see ML13100A230 and ML13273A299 for NRC's evaluation of these SAs). The FTF PORFLOW model discussed in the FTF PA (SRS-REG-2007-0002) was rerun using the updated inventories for the diversion boxes for the most risk-significant radionuclides or what is referred to as "sensitivity run radionuclides" (SRR-CWDA-2020-00055). The FTF GoldSim model was also rerun with the added FDB-5 and FDB-6 inventories. No PORFLOW deterministic sensitivity analysis or GoldSim probabilistic sensitivity analysis were performed given the low risk and use of a bounding inventory. A discussion of model scope and quality assurance for this model revision are both documented in *Radionuclide Transport Modeling in Support of the Special Analysis for F-Area Diversion Box 5 and Diversion Box 6* (SRR-CWDA-2020-00046).

DOE prepared this SA considering the Tanks 18/19 and Tanks 5/6 SAs. DOE simply added two new sources to represent FDB-5 and FDB-6 (Figure 9). The contributions to peak dose from the diversion boxes were negligible. The updated SA estimate for the maximum dose to a future hypothetical member of the public within 10,000 years and resulting from waste potentially remaining in FDB-5 is 6×10^{-5} mSv/yr (0.006 mrem/yr) in Sector C and from waste potentially remaining in FDB-6 is 1×10^{-4} mSv/yr (0.01 mrem/yr) in Sector D and is primarily associated with Technetium (Tc)-99 and Neptunium (Np)-237 (SRR-CWDA-2020-00055). The 1-m doses to an inadvertent intruder were also insignificant with the largest dose less than $< 3 \times 10^{-4}$ mSv/yr (0.03 mrem/yr) compared to the 0.7 mSv/yr (70 mrem/yr) dose from all sources.

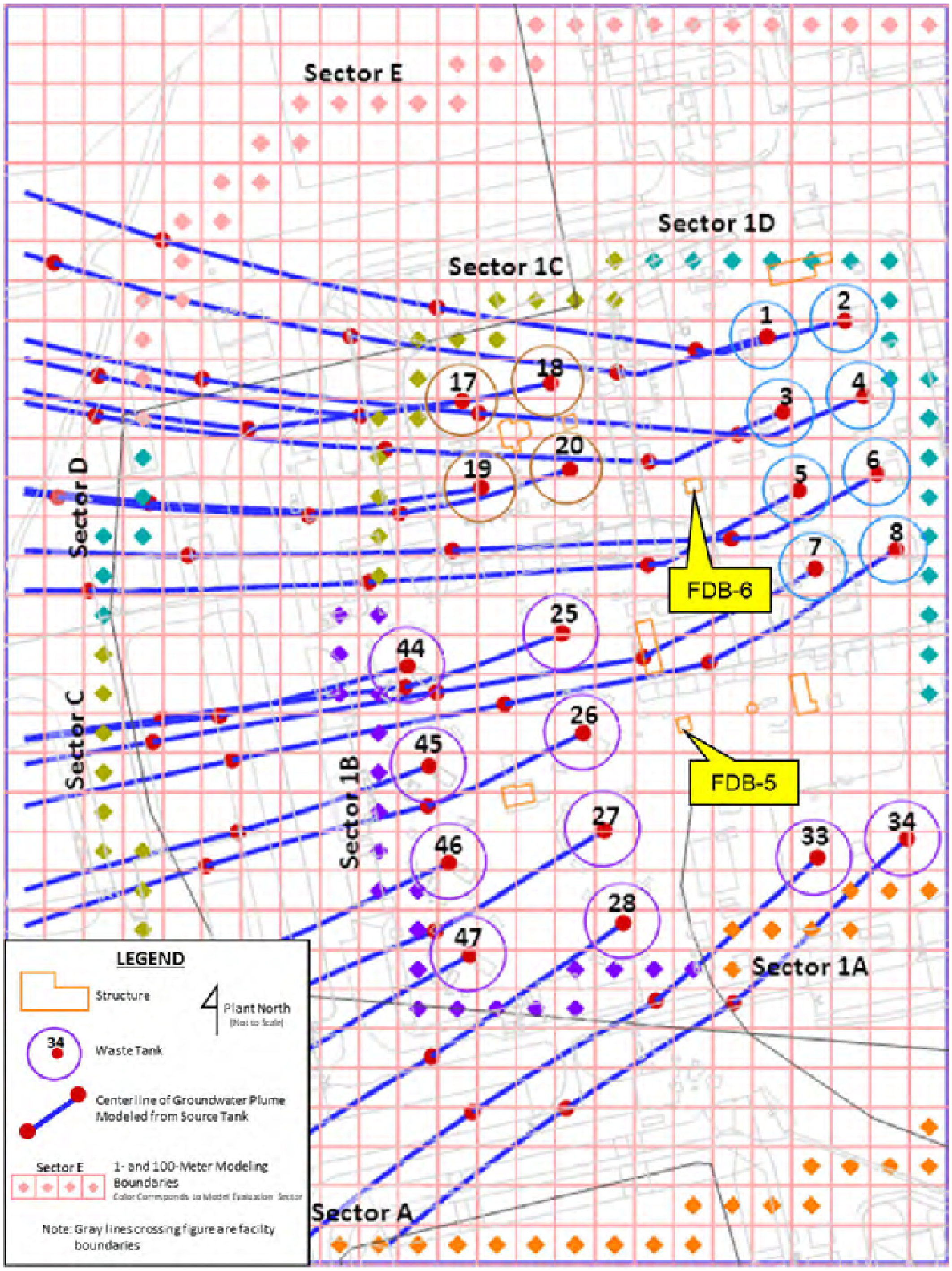

Figure 9. Map of FTF PA Model Showing Locations of FDB-5 and FDB-6 Sources.

Removal to the Maximum Extent Practical

DOE argued that further waste removal was not technically practical. To support its decision to not pursue additional waste removal from the diversion boxes, DOE indicated that (i) no specific technologies to retrieve waste from the diversion boxes were readily available (e.g., would need to develop robotic equipment small enough to fit inside the diversion box; or removal technologies would need to be developed for waste that may be in the jumpers); (ii) the benefit of additional removal is low, and (iii) the worker dose and other costs are not justified.

There are three categories of cleaning technologies that could be deployed including the following:

1. Mechanical cleaning
2. Chemical cleaning
3. Vacuum removal technologies

To improve efficiency of mechanical cleaning over previous water washing of the diversion boxes would entail incorporation of a more abrasive process to remove any potential residual radioactivity on internal surfaces of the diversion boxes or jumpers. Development and testing of an enhanced mechanical method would need to be conducted with uncertain benefit. Chemical cleaning does not appear necessary given that FDB-5 and FDB-6 were only used to transfer soluble supernate. Therefore, the benefit of employing a chemical cleaning technology in FDB-5 and FDB-6 is uncertain. Finally, given the small volume of residual waste on the bottom of FDB-6, inaccessibility of waste in jumpers, and the existence of obstructions in the diversion box such as jumpers/pedestals[10], the benefit of deployment of a vacuum-cleaning technology also appears uncertain. Deployment of any of these new technologies would also require removal of the cell covers or coring a large new access port, as well as erection of a containment structure and installation of portable ventilation to control the spread of contamination.

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[10] While Mantis technology was used to clean Tanks 18 and 19, it is large and would be difficult to maneuver inside a relatively small, congested diversion box. Development of a smaller robotic platform with vacuum capability would be needed with questionable benefit.

Summary and Evaluation of Alternative Grout Request Review Summary

SC DHEC requested that NRC staff review SRR's request for approval to use alternate fill materials for operational closure of tank farm ancillary structures, such as FDB-5 and FDB-6 at the F-Area tank farm (SRR-CWDA-2021-00010). Bulk fill reducing tank grout (mix LP#8-16; C-SPP-F-00055) and clean cap grout (C-SPP-Z-00012) were the only two tank fill grouts previously approved for use in the Consolidated General Closure Plan for F-Area and H-Area Waste Tank Systems (SRR-CWDA-2017-00015, Revision 0). Grout evaluations performed by SRR in support of closing FDB-5 and FDB-6 identified two other cementitious materials that DOE prefers to use to fill ancillary structures at the tank farms (i.e., low-slump, non-structural concrete (mix A2000-6-0-2-A; C-DCF-G-00397) and zero-bleed, controlled low-strength material (mix ZB-CLSM, which is the same as zero-bleed, structural flowable fill with no. 8 stone or ZB-FF-8-D; C-SPS-G-00096).

Low-Slump Concrete (mix A2000-6-0-2-A) has a 28-day compressive strength of 13,790 kPa (2000 psi) and a maximum slump of 15.2 cm (6 in; C-SPS-G-00096, Attachment 5.3). This mix contains neither pozzolan nor slag but does include 1.9-cm (¾-in) coarse aggregate (C-SPS-G-00096, Attachment 5.3). Admixtures included in the mix are air-entraining (only used as required) and water-reducing admixtures. This mix was placed inside the sumps of FDB-5 and FDB-6, where it mounded due to its low slump until the sump drain and overflow drain openings were sealed (C-SPS-G-00096; SRR-CWDA-2021-00010; C-DCF-G-00397). Low-slump concrete must only plug openings in the sump so that when the more flowable grout mix ZB-CLSM/ZB-FF-8-D is placed into the diversion box, it does not uncontrollably flow into other parts of the system. Low-Slump Concrete appears appropriate to perform this task. Low-Slump Concrete was allowed to gel before the diversion box was filled with grout mix ZB-CLSM/ZB-FF-8-D). Concrete mix A2000-6-0-2-A represents the smallest volume fraction that would be placed into ancillary equipment.

Grout mix ZB-CLSM/ZB-FF-8-D (Figure 10) is proposed by SRR as bulk fill grout for filling diversion boxes (SRR-CWDA-2021-00010). SRR indicates that ZB-CLSM/ZB-FF-8-D is easy to use, highly flowable, and produces low bleed due to its admixtures (viscosity modifier and high range water reducer). It is self-consolidating and self-leveling without vibration, and able to fill available space without leaving voids. Grout Mix ZB-CLSM/ZB-FF-8-D is similar to but not the same as a slag-free tank grout mix like LP#8-16. The former lacks slag and instead contains more fly ash; their water-to-cement (w:cm) ratios and quantities of cementitious materials and aggregate also differ (see Table 3.5-1 of SRR-CWDA-2021-00034 for mix comparison). Grout mix ZB-CLSM/ZB-FF-8-D has a 28-day minimum compressive strength of 345 kPa (50 psi) and a 90-day compressive strength of 6,895 kPa (1000 psi; C-SPS-G-00096). Given the 0.9-m (3-ft)-thick reinforced cover, a compressive strength of 13,790 kPa (2000 psi) to serve as an inadvertent intruder barrier does not appear necessary. Grout mix ZB-CLSM/ZB-FF-8-D represents the largest volume fraction placed into FDB-5 and FDB-6. Based upon the similarity between tank fill grout LP#8-16 and ZB-CLSM/ZB-FF-8-D, if ancillary structures, such as diversion boxes, contain negligible amounts of contamination such that chemically imparting reducing conditions on infiltrating water is unnecessary, then grout mix ZB-CLSM/ZB-FF-8-D will likely function in a similar manner to provide structural stability to ancillary structures.

Figure 10. Zero-bleed, Structural Flowable Fill with No. 8 Stone (ZB-FF-8-D) Grout Samples. Image Credit: SREL Doc-R-21-0003, Figure 8.

A separate evaluation of the alternative grout formulation request was conducted, and NRC staff conclude that the proposed alternative grouts (i.e., Low-Slump Concrete mix A2000-6-0-2-A and Zero-Bleed, Structural Flowable Fill with No, 8 stone (ZB-FF-8-D)), appear to be acceptable. Given the apparent low risk associated with residual waste that may be present in the FDB-5 and FDB-6 diversion boxes, NRC staff concur that a chemically reducing grout is likely unneeded to fill the diversion boxes.

Conclusions:

NRC findings related to *Inventory and Final Risk Estimates* include the following:

- Although no inventory was developed for diversion boxes, such as FDB-5 and FDB-6, in the FTF PA, DOE developed an inventory for these diversion boxes to perform a SA to estimate potential doses and support closure of the ancillary equipment. While there is significant uncertainty in the approach used to develop the inventory, NRC staff concludes that the approach used was reasonable given the expected low risk-significance of residual waste remaining in the diversion boxes compared to other sources at the FTF.
- NRC recommends that DOE look for opportunities to validate the methods used to develop the ancillary equipment inventory in the FTF PA, including the use of characterization and sampling to support the assumed low risk estimates of ancillary equipment. This will be especially important for potentially plugged transfer lines and jumpers.
- The results of the SA using the estimated inventories for FDB-5 and FDB-6 reveal negligible contributions to overall peak dose at FTF. The updated SA estimated the maximum potential dose to a future hypothetical MOP resulting from the waste in FDB-5 at 6×10^{-05} mSv/yr (0.006 mrem/yr) and from FDB-6 at 1×10^{-04} mSv/yr (0.01 mrem/yr).
- Given the apparent low risk associated with residual waste that may be present in the FDB-5 and FDB-6 diversion boxes, NRC staff concur that waste has been removed to the maximum extent practical.
- In future documentation, DOE should clarify the reason for abandonment of jumpers in the diversion boxes and the expected radiological status of the abandoned jumpers (e.g., the jumpers were plugged and were abandoned prior to waste dissolution; or the jumpers were not plugged or were plugged and abandoned after attempted waste dissolution) to provide a stronger basis for the assumptions that went into estimating the residual volume and concentration of waste remaining in the diversion boxes, particularly since the interior of these jumpers cannot be easily characterized.

NRC findings related to *Grout Performance and Waste Stabilization* include the following:

- Bulk fill reducing tank grout (mix LP#8-16 of C-SPP-F-00055) and clean cap grout (C-SPP-Z-00012) were the only two tank fill grouts previously listed for use in the Consolidated General Closure Plan for F-Area and H-Area Waste Tank Systems (SRR-CWDA-2017-00015, Revision 0). Grout evaluations performed by SRR in support of closing FDB-5 and FDB-6 identified two other cementitious materials that DOE prefers to use to fill ancillary structures at the tank farms: low slump, non-structural concrete (mix A2000-6-0-2-A) and a zero-bleed, controlled low-strength material (ZB-CLSM/ZB-FF-8-D; C-SPS-G-00096).
- Low-Slump Concrete (mix A2000-6-0-2-A) is not meant to be a structural concrete, but only needs to plug openings in the sump, so that when the more flowable ZB-CLSM/ ZB-FF-8-D is placed into the diversion box, it does not uncontrollably flow out into other

> parts of the system. This mix appears appropriate to perform this task. Based upon the similarity between tank fill grout LP#8-16 and ZB-CLSM/ZB-FF-8-D, if ancillary structures, such as diversion boxes, contain insignificant quantities of waste such that chemically imparting reducing conditions on infiltrating water is unnecessary, then ZB-CLSM/ZB-FF-8-D will likely function in an equivalent physical manner to provide structural stability to ancillary structures.

In this report, there is no significant change to the NRC staff overall conclusions from the NRC Technical Evaluation Report (TER) for the FTF dated October 2011 (ADAMS Accession No. ML112371751) or the NRC TER for the HTF dated June 2014 (ADAMS Accession No. ML14094A496) regarding compliance of the DOE disposal actions with the requirements of the performance objectives in 10 CFR Part 61, Subpart C. NRC staff will continue to monitor DOE activities in this area under (MFs) 1.1, “Final Inventory and Risk Estimates,” 1.4, “Ancillary Equipment Inventory”, 1.5, “Waste Removal (As it Pertains to ALARA)”; 3.4, “Grout Performance”, and 3.6, “Waste Stabilization (As it Impacts ALARA),” under NRC staff’s Tank Farms Monitoring Plan (ADAMS Accession No. ML15238A761).

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Appendix A

Summaries of Primary Documents:

C-DCF-G-00397. "Populate Mix Design Tables, Attachment 5.5" (Design Change Form). November 19, 2015. [ADAMS Accession No. ML21139A044]

This Design Change Form is associated with Specification C-SPS-G-00096, Revision 3, because the original Attachment 5.5, pages 1–4 were not completed in terms of the Mix Design Tables for many of the mixes. The associated change is to populate the mix design tables for the various concretes, grouts, and CLSM. An important aspect of this document is the following list that provides mix component descriptions and sources (i.e., vendors and vendor locations)

(9) Mix Component Descriptions and Sources.

(9a) Cement is Type I/II by Argos from Harleyville, South Carolina

(9b) Potable water from the City of Jackson, SC Municipal Water Supply

(9c) Sand is supplied by South Carolina Minerals (SCM) located in Beech Island, South Carolina

(9d) Pozzolan is Class F by SEFA Group located in Wateree, South Carolina

(9e) 3/8" coarse aggregate is supplied by Aggregates USA from Dogwood Quarry #8 located in Appling, Georgia

(9f) 3/4" coarse aggregate is supplied by Aggregates USA from Dogwood Quarry #67 located in Appling Georgia

(9g) 3/4" coarse heavyweight aggregate for the shielding concrete is Vulcan Materials Company, #67 from the Pineville Quarry in Charlotte, North Carolina.

(9h) Retarding Admixture is Daratard 17 Type B & D and Recover Type D by W. R. Grace

(9i) Water Reducing Admixture is WRDA 35 Type A & D and Mira 85 Type A & F by W. R. Grace

(9j) Air-Entraining Admixture is Darex II by W. R. Grace

(9k) High Range Water Reducing admixture is Adva 380 Type F and Adva Cast 575 Type A & F by W. R. Grace

(9l) Viscosity Modifier Admixture (VMA) is EXP 958 Type S & F by W. R. Grace

C-DCF-G-00400. Blankenship, J.K. "Revise 'Designing, Furnishing and Delivery of Ready Mixed Concrete, Grout and CLSM (U)' Specification (Design Change Form)." Revision 0. February 28, 2018. [ADAMS Accession No. ML21139A043]

This Design Change Form is associated with Specification C-SPS-G-00096, Revision 3, because the original specification contained incorrect admixture information for Zero-Bleed, Structural Flowable Fill Concrete with No. 8 stone (ZB-FF-8-D). The viscosity modifying admixture is WR Grace EXP-958 in the amount of 1.6 L/cubic meter (41.25 oz/cubic yard); the high-range water reducer is WR Grace Adva® Cast 575 in the amount of 3.2 L/cubic meter (80 oz/cubic yard), and the set accelerator is a maximum of 49.9 L/cubic meter (10 gal/cubic yard), but the base case for ZB-FF-8-D is that no set accelerator is used, and the amount added depends on the desired set time. Approved set accelerators include WR Grace DCI, which is compatible with the high-range water reducer used in this mix. The amount of water in the set accelerator must be subtracted from the amount of mixing water added.

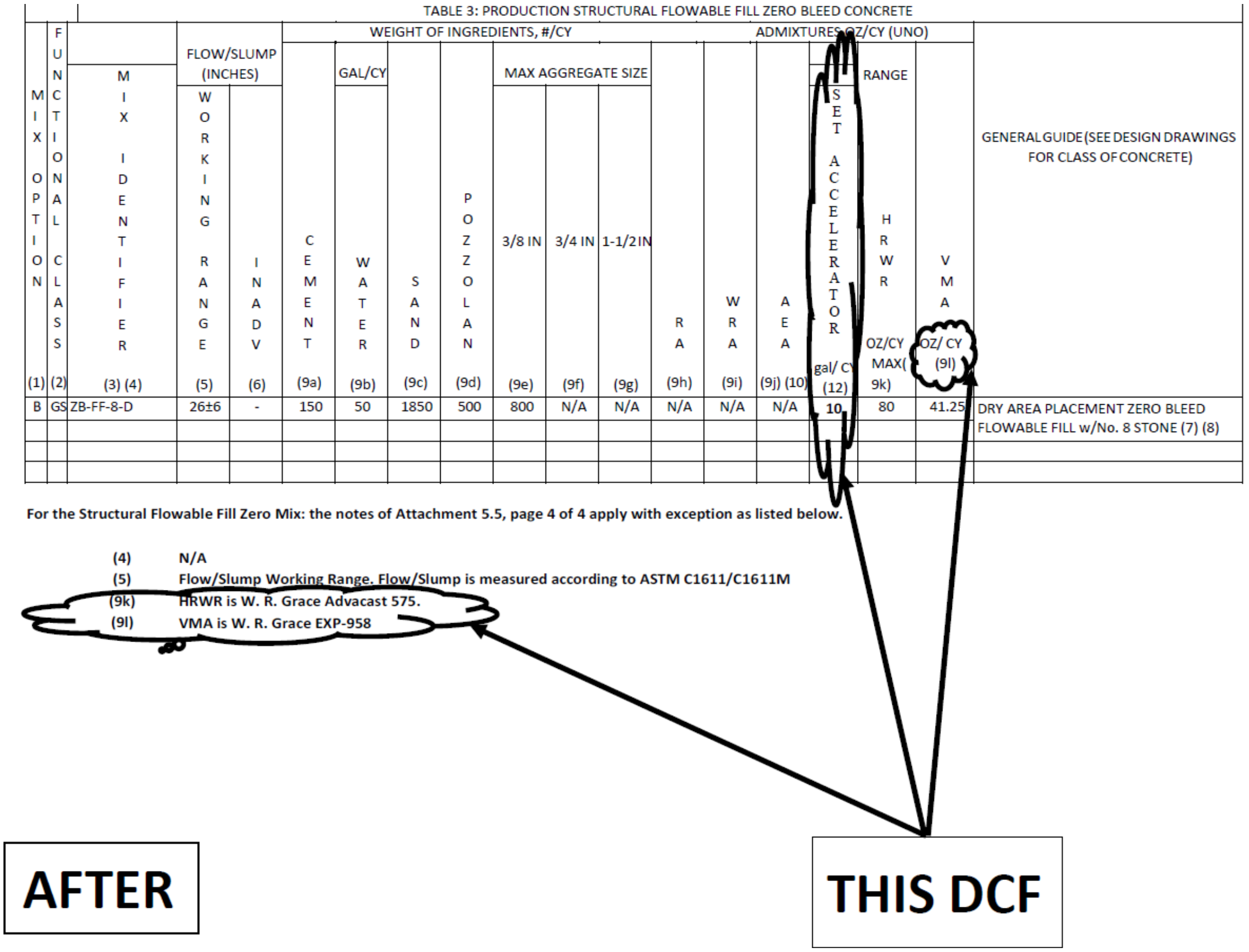


TABLE 3: PRODUCTION STRUCTURAL FLOWABLE FILL ZERO BLEED CONCRETE

MIX OPTION (1)	FUNCTIONAL CLASS (2)	MIX IDENTIFIER (3) (4)	FLOW/SLUMP (INCHES)		WEIGHT OF INGREDIENTS, #/CY							ADMIXTURES OZ/CY (UNO)						GENERAL GUIDE (SEE DESIGN DRAWINGS FOR CLASS OF CONCRETE)
						GAL/CY			MAX AGGREGATE SIZE							RANGE		
			WORKING RANGE (5)	INADV (6)	CEMENT (9a)	WATER (9b)	SAND (9c)	POZZOLAN (9d)	3/8 IN (9e)	3/4 IN (9f)	1-1/2IN (9g)	RA (9h)	WRA (9i)	AEA (9j) (10)	SET ACCELERATOR gal/ CY (12)	HRWR OZ/CY MAX(9k)	VMA OZ/ CY (9l)	
B	GS	ZB-FF-8-D	26±6	-	150	50	1850	500	800	N/A	N/A	N/A	N/A	N/A	10	80	41.25	DRY AREA PLACEMENT ZERO BLEED FLOWABLE FILL w/No. 8 STONE (7) (8)

For the Structural Flowable Fill Zero Mix: the notes of Attachment 5.5, page 4 of 4 apply with exception as listed below.

(4) N/A
(5) Flow/Slump Working Range. Flow/Slump is measured according to ASTM C1611/C1611M
(9k) HRWR is W. R. Grace Advacast 575.
(9l) VMA is W. R. Grace EXP-958

AFTER

THIS DCF

<u>C-SPS-G-00096. Baldwin, G.R. “Designing, Furnishing and Delivery of Ready Mixed Concrete, Grout and CLSM (GS & Procurement Specification).” Revision 3. [ADAMS Accession No. ML21139A041]</u>

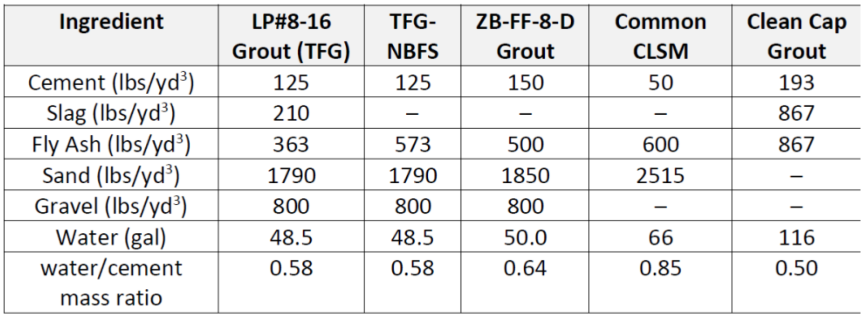
Supplier of ready mixed concrete, grout and CLSM shall design, adjust, and qualify the various cementitious material mixes to achieve desired attributes (e.g., compressive strength, slump, material components and air entrainment) using fine and coarse aggregate available locally near the point of production, unless specified otherwise. Moisture content of fine and coarse aggregates used should be monitored and recorded, and mix water quantity should be adjusted, accordingly. Mix temperatures should not exceed 32 °C (90 °F) at the point of delivery.
All design mixes should be tested at a temperature within 5.6 °C (10 °F) of the maximum allowable temperature. Documentation (i.e., Batch Tickets) should be provided that identifies the material components by brand, type, class, grade, or source of the material components corresponding to Supplier material identification numbers for the material components.
Batch tickets provided by suppliers to support traceability should be legible to end-users who monitor operations. Section 3.2.2 of the specification concerns design mixes and refers the reader to Attachment 5.3 and tables of Attachment 5.5. Once the supplier has had a design mix approved such that it becomes a production mix, adjustments to the production mix, material components of the production mix, and the source of material components of the production mix may not be made without prior approval from Savannah River Nuclear Solutions (SRNS).
New adjustments and changes cause a new cementitious material mix to revert to being an

unapproved design mix that must be qualified and resubmitted to SNRS for acceptance. Section 3.2.2.2 of the specification concerns concrete, including Low-Slump Concrete (mix A2000-6-0-2-A) proposed for use to seal diversion box sumps. Section 3.2.2.3.8 pertains to low shrinkage grout and extended set low-shrinkage grout design mixes, which may be of interest to tank grouting operations that seek to minimize development of preferential flow pathways. Section 3.2.2.4 concerns CLSM, including mix EXE-X-P-0-X, which was considered for potential use as a future tank closure grout (SREL Doc. R-21-0001; SRR-CWDA-2020-00045). Section 3.2.2.5 of the specification concerns Zero-Bleed, Structural Flowable Fill Concrete, ZB-FF-8-D, also known as Zero-Bleed CLSM (ZB-CLSM). This mix was used to fill ancillary equipment at the F-Area Tank Farm, namely FDB-5 and FDB-6. ZB-CLSM is similar to but not the same as a non-reducing LP#8-16 tank grout, as it has a larger w:cm ratio and different proportions of cementitious materials (SRR-CWDA-2020-00061; SRR-CWDA-2021-00034). Procurement specification C-SPS-G-00096 (Revision 3) contained incorrect admixture information for ZB-FF-8-D, which was then corrected in Design Change Form C-DCF-G-00400, as summarized above.

Section 4.4 of this specification concerns inspection/testing requirements for production mixes, also addressed in Attachment 5.4. Compressive strength cylinders of various diameters and lengths require variable numbers of cylinders to be cast. For example, one cylinder may be tested at 7 days, two cylinders at 28 days, with two cylinders placed on hold. If early compressive strength requires verification, an additional cylinder may be cast to ensure strength test requirements are met. If the 28-day compressive strength test meets design requirements, cylinders placed on hold may be discarded, unless required for testing at 90 days due to the mix containing pozzolan (e.g., Class F fly ash by SEFA Group, Wateree, South Carolina).

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, 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 but not the same as Zero-Bleed 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 but not to be confused with TCG-NBFS nor with Zero-Bleed CLSM mix ZB-FF-8-D. To clarify the similarities and differences of the grout mixes discussed in this and other reports, Table 3.5-1 of SRR-CWDA-2021-00034 is reproduced here:



Ingredient	LP#8-16 Grout (TFG)	TFG-NBFS	ZB-FF-8-D Grout	Common CLSM	Clean Cap Grout
Cement (lbs/yd^3)	125	125	150	50	193
Slag (lbs/yd^3)	210	–	–	–	867
Fly Ash (lbs/yd^3)	363	573	500	600	867
Sand (lbs/yd^3)	1790	1790	1850	2515	–
Gravel (lbs/yd^3)	800	800	800	–	–
Water (gal)	48.5	48.5	50.0	66	116
water/cement mass ratio	0.58	0.58	0.64	0.85	0.50

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 (called common CLSM in the previous table) had w:cm = 0.847.

The 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 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 while reproducing the formulated proportions of cementitious materials vs. sand in monolithic grout recipes.

Reducing tank grout/TCG maintained the highest *pH*, necessary for corrosion protection, with TCG-NBFS having the next highest *pH*. Lowest E_h values were attained for all samples equilibrated in an anaerobic Coy Chamber, and the next-lowest values were attained for samples equilibrated with a purged nitrogen atmosphere in a glove box; highest values were associated with batch samples open to the lab atmosphere. For more detail, see SRR-CWDA-2020-00061 Table 1, as is reproduced in this appendix.

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 CO_2-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 6 wt% measured via XRF). Monosulfoaluminate is produced via reaction between tricalcium aluminate (a primary cement phase) and ettringite (a cement hydration product). For more detail, see SRR-CWDA-2020-00061 Tables 2 and 3, as is reproduced in this appendix.

SREL Doc. R-21-0003 (or SRRA 099188-000015). Seaman et al. "CLSM Characterization: Data Report." Aiken, South Carolina: Savannah River Ecology Laboratory. September 2021. [ADAMS Accession No. ML21336A379]

This document provides test results obtained by the Savannah River Ecology Laboratory (SREL) for grout performance attributes of proposed Controlled Low-Strength Material (CLSM) Tank Closure Grout (TCG) prepared from grout mix ZB-FF-8-D with w/cm ratio of 0.595. SREL measured saturated hydraulic conductivity of four CLSM grout samples that had aged a

minimum of 316 days and compared these results with those reported by Wood Environment & Infrastructure Solutions, Inc. (SRN19-00082.0) for grout samples aged 90 days.
SREL conducted saturated hydraulic conductivity tests in accordance with ASTM D 5084-16a, Method F (Constant Volume Falling Head) using a flexible wall permeameter. SREL also estimated water retention or moisture characteristic of three of the four grout samples tested for saturated hydraulic conductivity. Finally, SREL estimates of apparent tritium diffusion coefficient for two grout samples were 1.0×10^{-8} $cm^2 \cdot s^{-1}$ and 3.6×10^{-8} $cm^2 \cdot s^{-1}$ using a modified sample immersion method (Park et al., 2014); these results were similar to values for nitrate. SREL was unable to calculate chloride diffusion coefficient, however, because the error bars were too large (see their Figure 6). Nevertheless, the general trend in chloride concentration was similar to tritium.

Sample No.	Mean Hydraulic Conductivity (cm/s) at >300 days
A	2.3×10^{-8}
B	0.4×10^{-8}
C	3.7×10^{-8}
D	0.8×10^{-8}
Mean	$\mathbf{1.8 \times 10^{-8}}$

SRN19-0082.0. “Test Report—CLSM Proposed TCG Hydraulic Conductivity Test.” Revision 0. Atlanta, Georgia: Wood Environment & Infrastructure Solutions, Inc. May 7, 2020. [ADAMS Accession No. ML23087A006]

This document is a test report transmittal letter transmitting hydraulic conductivity test results for three samples of a proposed Controlled Low-Strength Material (CLSM) Tank Closure Grout (TCG) in its Attachment 1 to Savannah River Nuclear Solutions (SRNS). The tested CLSM grout samples were prepared from grout mix ZB-FF-8-D and had aged 90 days (SREL Doc. R-21-0003). The saturated hydraulic conductivity tests were conducted in accordance with ASTM D 5084-16a, Method F (Constant Volume Falling Head) using a flexible wall permeameter by Wood Environment & Infrastructure Solutions, Inc. under SRNS Subcontract No. 0000441257.

Sample No.	Mean Hydraulic Conductivity (cm/s) at 20 °C and 90 days
20014-1A	2.0×10^{-8}
20014-1B	1.1×10^{-8}
20014-1C	3.1×10^{-8}
Mean	$\mathbf{2.1 \times 10^{-8}}$

SRR-CWDA-2020-00011. “Industrial Wastewater Closure Module for F-Area Diversion Boxes 5 and 6, F-Area Tank Farm, Savannah River Site.” Revision 0. Aiken, South Carolina: Savannah River Remediation. February 2021. [ADAMS Accession No. ML21181A394]

The industrial wastewater closure module describes the method by which DOE developed inventories for materials remaining in FDB-5 and FDB-6 and plans to isolate the diversion boxes from the operating facilities at FTF. Inventories were assigned using the SRS WCS, which uses sampling, process history, and calculations/theoretical relationships to determine the inventory. Concentrations from WCS are used with information on the total affected surface area in the structures to calculate the inventory. A special analysis was conducted to determine the expected dose contributions from the diversion boxes. DOE concludes that the performance objectives are met and that the stabilized diversion boxes would be protective of human health and the environment. Additionally, the closure module concludes that further waste removal is not technically practical from an engineering perspective. Approval of the closure module by SC DHEC means that the state agrees that waste removal activities can cease and the stuctures can be stabilized. Following operational closure, DOE will be submit final configuration reports for FDB-5 and FDB-6 to SCDHEC.

SRR-CWDA-2020-00029. Layton, M. "Inventory Assignment at Closure for FDB-5 and FDB-6." Revision 1. Aiken, South Carolina: Savannah River Remediation. February 23, 2021. [ADAMS Accession No. ML21180A428]

This document discusses the development of the inventory for FDB-5 and FDB-6 to support performance assessment modeling and closure of these two pieces of ancillary equipment at FTF. The same 60 radionuclides were considered, and the same approach was used for developing the ancillary equipment inventory as that used in the FTF PA. Approximately 5 gallons (20 L) of residual sludge slurry was "conservatively" assumed to remain on the diversion box floor among other conservative assumptions that were validated based on comparison to 2020 FDB-5 characterization results.

SRR-CWDA-2020-00045. Flach, G. "Characterization and Assessment of CLSM Grouts for Potential Use in Waste Tank Operational Closures." Revision 0. Aiken, South Carolina: Savannah River Remediation. June 22, 2020. [ADAMS Accession No. ML22094A047.

This report evaluates two Controlled Low-Strength (CLSM) grout mix candidates (EXE-X-P-0-X and ZB-FF-8-D) for potential use as bulk fill tank grout when physical stabilization is necessary but radiochemical stabilization is not. Candidate tank fill grouts are flowable, self-leveling and self-consolidating without vibration. Requirements for grout set time under 24 hrs and zero bleed after 24 hrs were proposed to enable daily placement of fresh grout above hardened grout. Neither a grout recommendation nor a grout selection decision for tank closure were within the scope of this study. Because grout mix ZB-FF-8-D has already been used to close ancillary structures FDB-5 and FDB-6, the information on its properties contained within this report is generally relevant to ancillary structure closures in the tank farm facilities.

System One mixed both candidate CLSM grouts and performed fresh grout property measurements (i.e., slump flow, bleed and set time), compressive strength tests, and shrinkage tests. Wood Environment & Infrastructure Solutions, Inc. conducted saturated hydraulic conductivity tests on the grout specimens after 90 days had elapsed. The purposes of this characterization and assessment study were to (i) identify grout attributes affecting performance as a liquid waste tank bulk fill material (captured in their Table 3); (ii) define performance metrics, requirements, and goals (captured in their Table 3); (iii) assemble existing material property characterization data on the LP#8-16 reducing tank grout mix and the aforementioned CLSM grout mixes; (iv) identify key data gaps and acquire new CLSM material property data; (v) assess pros and cons of LP#8-16 and the two candidate CLSM grout mixes on an attribute-by-attribute basis (Section 4 and Tables 11 and 12 of the report), and (vi) recommend next steps for selection of a bulk fill tank grout for future waste tank operational closures (Section 5 of the report) when radiochemical stabilization is unnecessary based on tank inventory.

Potential use of an inexpensive grout mix denoted EXE-X-P-0-X will likely be abandoned for tank closure activities based on its characterization data. The mix produces an excessive amount of bleedwater (Table 8 of report; see also SREL Doc. R-21-0001 Figure 2). Additionally, its saturated hydraulic conductivity was only slightly lower than that of backfill soil and it may not have been able to maintain a *pH* high enough for corrosion protection. Finally, its compressive strength at 90 days was insufficient to meet the NRC-recommended 3,450 kPa (500 psi) threshold.

In contrast, Zero-Bleed CLSM mix ZB-FF-8-D was designed to produce no bleed-water 24 hrs after being placed. The ZB-FF-8-D grout mix formula is similar to the grout mix placed into Tanks 17F and 20F, and it has been used extensively at SRS for more than a decade, including during decommissioning of P- and R-Reactor complexes (SRNL-STI-2019-00009; Langton et al. 2010; Langton et al. 2011). In fact, the ZB-FF-8-D grout mix formed the basis for later development of the reducing tank grout mix LP#8-16 that has since been used to fill Tanks 5F, 6F, 12H, 16H, 18F, and 19F. The compressive strength of mix ZB-FF-8-D at 90 days exceeded both the NRC's 410 kPa (60 psi) requirement and the NRC's 3,450 kPa (500 psi) recommendation. Mix ZB-FF-8-D exhibited near-zero net bleed at 24 hrs (Table 9 of report) and no shrinkage. Its saturated hydraulic conductivity was roughly three orders of magnitude lower than that of backfill soil, and its *pH* was greater than 10 as is necessary for corrosion protection. In comparison to reducing tank grout mix LP#8-16, however, the reducing tank grout has higher compressive strength, lower saturated hydraulic conductivity, and higher *pH* than mix ZB-FF-8-D. There is also virtually no price difference between these two mix options. The report concluded by recommending that the effective diffusion coefficient and water retention properties of mix ZB-FF-8-D be characterized.

SRR-CWDA-2020-00055. "FDB-5 and FDB-6 Special Analysis for the Performance Assessment for the F-Tank Farm at the Savannah River Site." Revision 1. Aiken, South Carolina: Savannah River Remediation. February 2021. [ADAMS Accession No. ML21180A433]

The SA provides information about the impact of new information on the results and conclusions of the FTF PA. After issuance of Rev. 1 to the FTF PA, two other SAs were prepared for the FTF—the Tanks 18/19 and Tanks 5/6 SAs in 2010 and 2012, respectively. This third SA is focused on evaluating the impact of the residual inventory estimated to remain following closure of FDB-5 and FDB-6 on the validity of the FTF PA conclusions. The results of the SA reveal no change in the estimated peak doses for the 100-m groundwater pathway dose for the 1000, 10,000, and 100,000-yr evaluation periods; additionally, the inadvertent intruder dose remains unchanged. The SA concludes that there is reasonable assurance that FTF disposal actions meet the requirements of DOE M 435.1-1, NDAA Section 3116, and that there is no impact to the conclusions in the FTF PA and supporting SAs.

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]

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 but not the same as Zero-Bleed 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). Test conditions were (i) open, oxidizing atmosphere, (ii) N_2-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 (also Table 17 of SREL Doc. R-21-0001), 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 (also Table 13 and Tables 14–16 of SREL Doc. R-21-0001), reproduced next. Updates to the tank farm waste release model are anticipated to use these new data to address the (i) impact of infiltrating ground water on grout pore-water chemistry as a function of time; (ii) anticipated mineral states; and (iii) solubility-controlling mineral phases selected per element.

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)

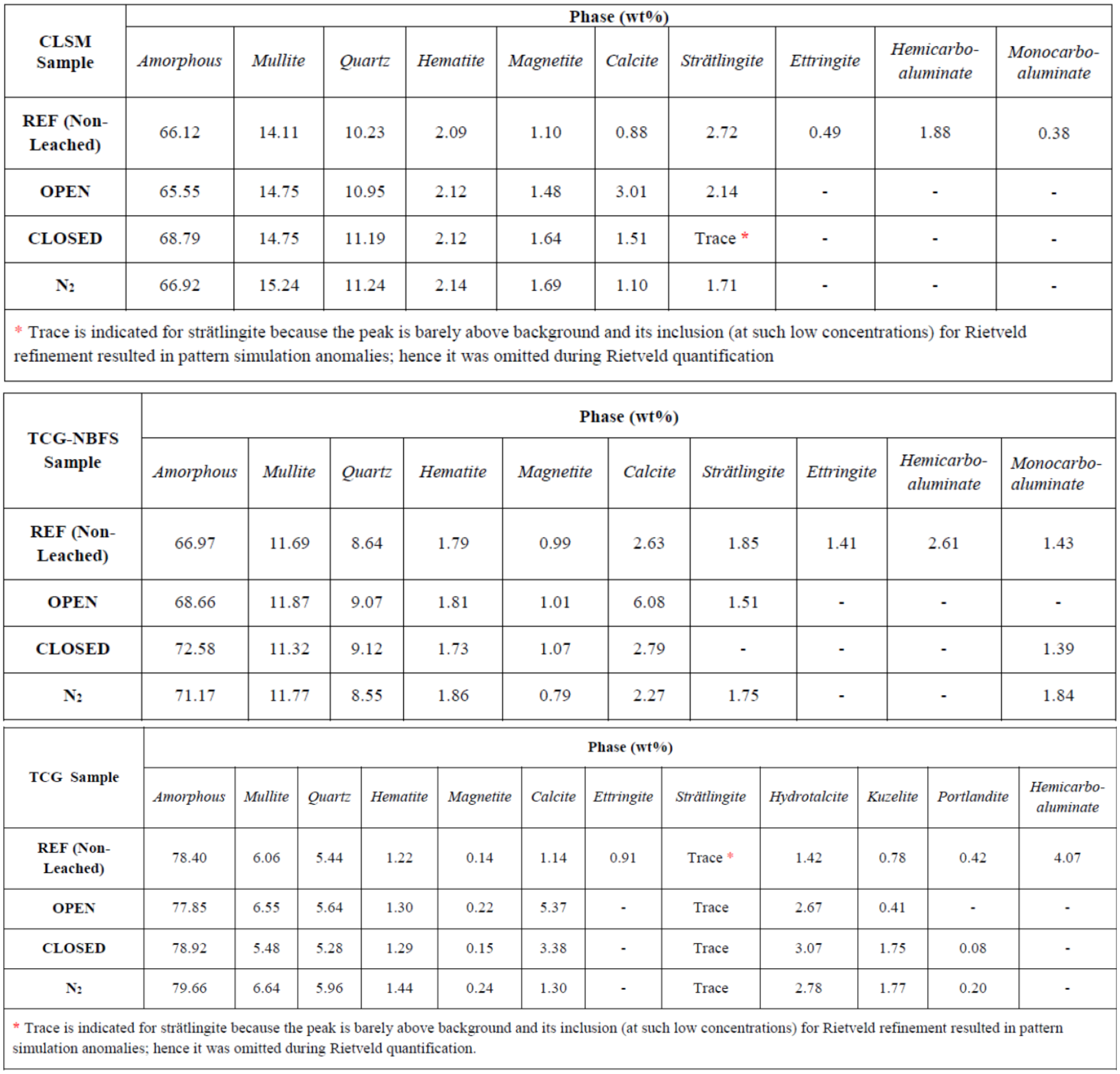
	pH	Eh (volts)	Ca^{2+} (molar)	Na^{+} (molar)	Mg^{2+} (molar)	K^{+} (molar)
Leaching solution prescribed in SRNL-STI-2012-00404						
	4.68		2.1E-06	8.7E-06	1.3E-06	
Chemical Conditions of Reducing Grout Pore Water (SRNL-STI-2012-00404; SRR-CWDA-2016-00086)						
Red. Region II	11.1	-0.47	4.0E-03	1.0E-03		
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.

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 approximately 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 purged 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 pH Region II and Region III (SRNL-STI-2012-00404). Longer oxygen exposure may result in higher E_h for reducing tank grout. For non-slag-bearing candidate tank grouts TCG-NBFS 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.

SRR-CWDA-2021-00010, Attachment 1: "Technical Justification for Use of Low Slump Concrete and Zero-Bleed CLSM for Operational Closure of F and H Tank Farm Ancillary Structures" in *Request for Approval to Use Alternate Fill Materials for Operational Closure of Tank Farm Ancillary Structures at the Savannah River Site, Aiken, South Carolina [Letter from Kenneth Wells (SRR) to Shawn Clarke (SC DHEC)].* Aiken, South Carolina: Savannah River Remediation. February 3, 2021. [ADAMS Accession No. ML23268A450]

Attachment 1 to SRR-CWDA-2021-00010 provides the technical basis to support Savannah River Remediation's request for SCDHEC approval of a "Low Slump Concrete" and "ZB-CLSM" as alternate fill materials for the operational closure of F-Area and H-Area ancillary structures. Bulk fill reducing tank grout (mix LP#8-16; C SPP-F-00055) and clean cap grout (C-SPP-Z-00012) were the only two tank fill grouts previously approved for use in the Consolidated General Closure Plan for F Area, and H Area Waste Tank Systems (SRR-CWDA-2017-00015, Revision 0).

Attachment 1 lists performance assumptions for grout used to fill high-level waste tanks. The same performance assumptions do not necessarily to ancillary equipment. The ancillary structures would be filled with grout or other materials, as practical, to eliminate subsidence potential. The ancillary structure fill grout, however, is not credited as a deterrent to the inadvertent intruder (per FTF PA Section 3.2.2.6.2, the FTF closure cap and concrete structures will serve as a deterrent to the inadvertent intruder). Furthermore, the low hydraulic conductivity of the grout used to fill ancillary equipment is not being relied to limit flow through the ancillary structures nor is the initially high pH relied for corrosion resistance.

SRR-CWDA-2021-00034. Flach, G. "Chemical and Physical Evolution of Tank Closure Cementitious Materials." Revision 0. Aiken, South Carolina: Savannah River Remediation. April 2021.

To support the upcoming HTF and FTF PA revisions, this report updated prior studies of expected distribution coefficients (K_ds), solubility controls, steel corrosion rates, saturated hydraulic conductivity, effective diffusion coefficient, and physical degradation of cementitious materials as functions of time. The chemical evolution analysis was performed with Geochemist's Workbench and PHREEQC using custom thermodynamic databases.
The physical evolution analysis was performed using simple abstractions that were solved analytically. Several cementitious materials were analyzed, including reducing tank grout (LP#8-16, also referred to as Tank Fill Grout/TFG and Tank Closure Grout/TCG), aggregate-free clean cap grout (as placed into the upper zone of Tank 16H), Zero-Bleed CLSM (ZB-FF-8-D), Tank Fill Grout with No Blast Furnace Slag (TFG-NBFS, also referred to as Tank Closure Grout with No Blast Furnace Slag/TCG-NBFS) and the CLSM known as EXE-X-P-0-X (referred to as Common CLSM in Table 3.5-1 of this report).