PNNL-38053

Evaluation of Hanford 200 West Area Tank Farms (241-S/241-SX-/241-U tank farms) Physical Properties Data for Use in Development of West Area Tank Treatment (WATT) Processing

August 2025

BC Simpson
RA Peterson
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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

With the recent acceptance of West Area Tank Treatment disposition alternative for 200 West Area tanks at the Hanford Site by the State of Washington and the U.S. Department of Energy,[1] a review was initiated to identify the physical properties data available in the literature for the Hanford 241-S, 241-SX, and 241-U tank farms. The literature reviewed indicated that there is a relatively small set of useful data on physical properties of 200 West Area tanks, and the data that do exist are biased around a narrow range of tank samples. Much of the testing between the 1990s and mid-2010s was intended to support either enhanced sludge washing or feed delivery to the Pretreatment Facility at the Hanford Waste Treatment and Immobilization Plant. As such, some physical properties of 200 West Area samples were measured under conditions that are no longer relevant. Because of the distinctly different nature of many past processes at the 200 West Area compared to the 200 East Area, insight from waste testing in the 200 East Area waste should be used with caution, as there may be significantly different qualities in the physical properties data between these two areas (both in situ and as measured in laboratory analyses). Based on this assessment, there is a need to collect additional physical property data to support planning for 200 West Area retrievals.

Figure A.1 provides a strategic visual representation of the proposed 200 West Area waste processing system.

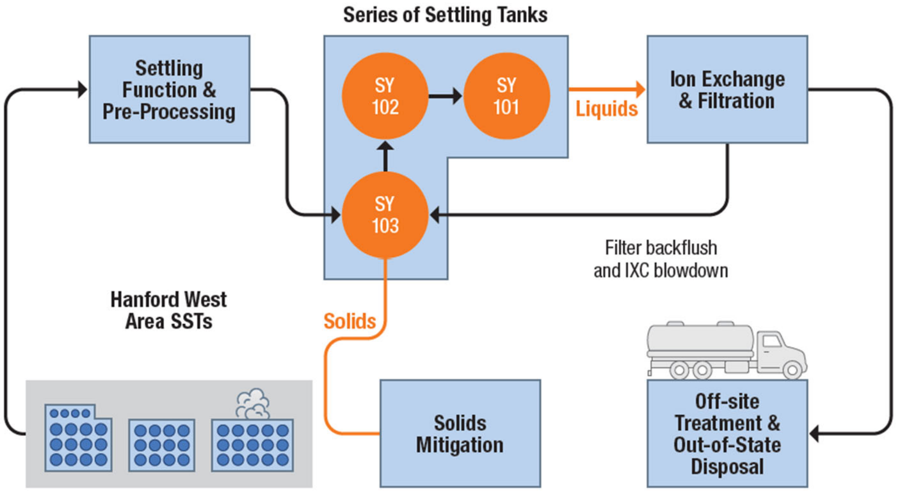

Figure A.1. West Area Tank Treatment Configuration

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[1] Final Approval Package on the Future of Tank Waste Cleanup at the Hanford Site Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) and Washington v. Energy Consent Decree, 2025. Case No 08-5085-RMP Changes. https://pdw.hanford.gov/document/AR-33193

Acronyms and Abbreviations

1C	1st Cycle Decontamination-BiPP waste
200E	200 East Area
200W	200 West Area
BBI	Best Basis Inventory
BiPP	bismuth phosphate process
CWR	Cladding Waste-REDOX
CWR1	REDOX cladding waste from 1952 to 1960.
CWR2	REDOX cladding waste from 1961 to 1967.
DE	diatomaceous earth
DFHLW	Direct Feed High-Level Waste
DFLAW	Direct Feed Low-Activity Waste
DOE	U.S. Department of Energy
DST	double-shell tank
NIT	$HNO_3/KMNO_4$ solution added during evaporator operation, also called Partial Neutralization Feed, PNF.
NQA-1	Nuclear Quality Assurance-1, ASME nuclear quality assurance standard for nuclear facilities
PNNL	Pacific Northwest National Laboratory
R	REDOX High-Level Waste (HLW) generated from 1952 to 1966.
R1	REDOX waste generated between 1952 and 1957.
R2	REDOX waste generated between 1958 and 1966.
RSltCk	Salt Cake precipitate from self-concentration in S and SX Farms.
REDOX	REDuction and Oxidation (S Plant)
S1	Salt cake waste generated from the 242-S Evaporator/crystallizer from 1973 until 1976.
S2	Salt cake waste generated from the 242-S Evaporator/crystallizer from 1977 until 1980.
SST	single-shell tank
WATT	West Area Tank Treatment
WTP	Hanford Waste Treatment and Immobilization Plant

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1.0 Background

From 1944 to 1989, the U.S. Department of Energy (DOE) Hanford Site, located in southeastern Washington state, produced plutonium for defense purposes. Legacy waste from these production processes is stored in waste tanks at the site. The Hanford Waste Treatment and Immobilization Plant (WTP) is being constructed to immobilize the waste in glass waste forms as either Direct Feed Low-Activity Waste (DFLAW) or Direct Feed High-Level Waste (DFHLW). However, the WTP is in Hanford's 200 East Area (200E), and the current infrastructure at Hanford is not capable of moving waste from the 200 West Area (200W) to 200E (Figure 1). In addition, even with future plans to commission the existing cross-site slurry line linking the 200W and 200E areas, WTP does not have the capacity to treat all the waste. Further, when these types of transfers were performed in the past, the transfer lines, pumps, junction boxes, and other interconnections were routinely prone to plugging/fouling (Servin et al. 2012).

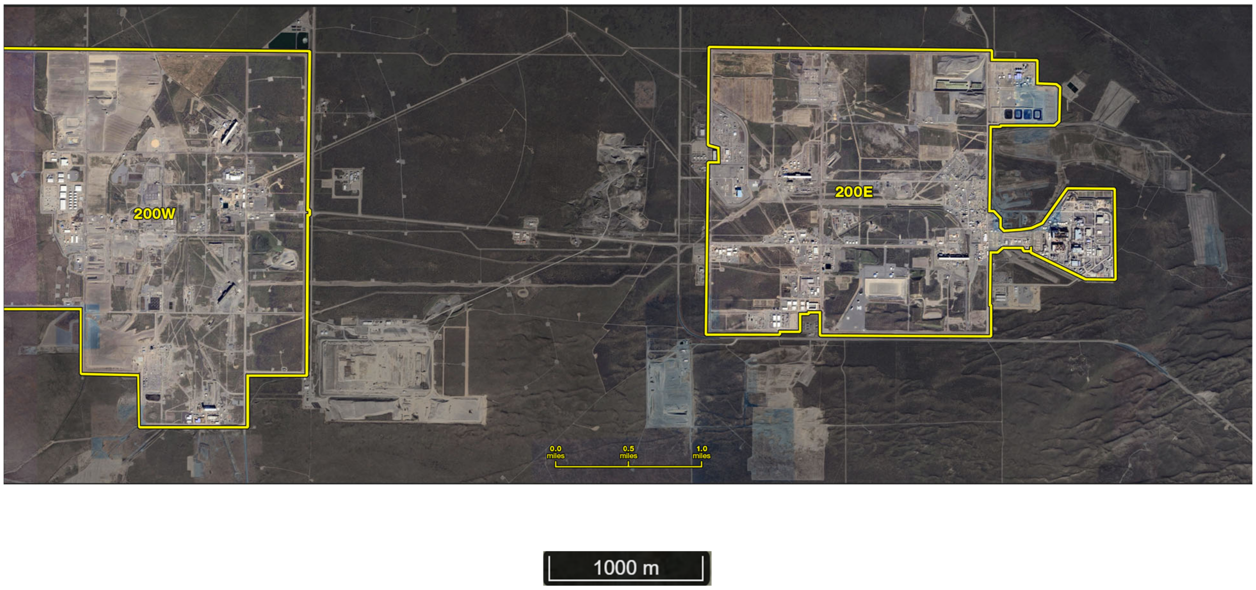

Figure 1. Hanford 200 Areas. The 200 West Area (left part of the image) is several miles from the 200 East Area. There is currently no active infrastructure to allow transfer of waste between the two locations. The WTP complex is at the far right of the image.

During the production mission at Hanford, wastes would accumulate or undergo phase transitions (gel or precipitate) in the lines and form blockages as transfers were performed between tanks and over the several-mile long cross-site transfer from 200W to 200E. There are also numerous radiological, chemical, and criticality safety (Leach and Stahl 1993; Whyatt et al. 1996) concerns related to moving wastes across the site using a pipeline, and even with an acceptable transportation method, there is very little space available in the double-shell tanks (DSTs) in 200E or 200W to store waste retrieved from 200W. Further complicating retrieval, there are only three DSTs in 200W. The cross-site slurry line, SLL-3160, has not been approved for use, and there is a rough-order-of-magnitude estimate in the tens of millions to prepare the line for operations (Servin et al. 2012). The current baseline uses the cross-site transfer line, but the slurry line is not scheduled to be ready until 2040. Reactivation of the cross-site supernatant line is projected to cost an additional $35 million or more, and the transfer will require several years to complete, resulting in a substantial capital expense (Eaton et al. 2018). Without a means to transfer waste from 200W to 200E, an alternative strategy for immobilizing those wastes is needed (Bernards et al. 2020; Bates 2022; National Academies of Sciences, Engineering, and Medicine 2020).

Milestone M-45-135 of the Tri-Party Agreement and consent decree established a milestone for retrieving waste from 22 tanks in Hanford's 200 West Area by 2040, including pretreatment of the low-activity portion of the waste for offsite disposal. Supernate (including dissolved saltcake and interstitial liquids) will be retrieved from single-shell tanks (SSTs) located in 200W, staged with pre-processing unit operations, then further separated (via settling and decanting) through SY-Farm and pretreated (via filtration and ion exchange). Specifically, this includes waste from 22 to 24 SSTs from S, SX, and U tank farms as well as DSTs 241-SY-101, 241-SY-102, and 241-SY-103. Figure 2 provides a simplified process diagram of the key features for the proposed retrieval effort.

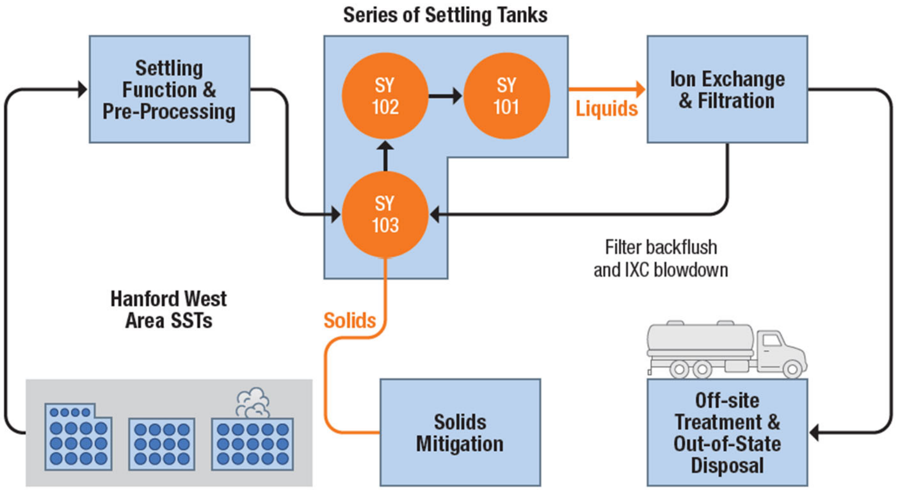

Figure 2. West Area Tank Treatment Configuration (tank farms, supporting infrastructure, and unit operations).

To support 200W SST retrievals and to manage the retrieved waste, a project called West Area Risk Management (WARM) was created to plan, design, and construct the 200W process modules and supporting infrastructure to perform the pretreatment function of the project. This mission presents several technical challenges, including but not limited to the development of a flowsheet, managing organics for treatment, solids management, and developing waste acceptance criteria. The current preliminary flowsheet (Nguyen 2025) suggests that solids will reach Group A levels, e.g. above the operating threshold height, in the SY farm receipt tank (241-SY-103) approximately 3 years after waste retrievals start and there is currently no additional storage space for solids and no treatment option.

Once one of the SY farm tanks reaches Group A levels, retrievals will have to be suspended until there is a means to reduce solids levels and their accumulation in the receiving tank, SY-103. A review of existing information was therefore conducted to consolidate available information to support the development of waste management strategies for retrieval of waste from 200W SSTs.

The first processing plant at Hanford, T-Plant, was built in 1944 in the 200W chemical separations complex (Gephart 2010). From 1944 to 1952, the T-Plant separated plutonium (Pu) from the 100 Area reactors using a bismuth phosphate purification process (Colburn and Peterson 2021). In the 1950s, the REDOX (REDuction and OXidation) plant in 200W was commissioned to increase Pu recovery efficiency with a more efficient solvent extraction process (Gephart 2010). An additional plant, U-Plant, was built in 200W and recovered uranium from tank waste from 1952 to 1958 (Gephart 2010).

200W has seven tank farms: 241-T, -TX, -TY, -U, -S, -SX, and -SY. These farms have only SSTs except for the 241-SY Farm, which has the three DSTs. The 200W tanks received waste from the nearby separation plants: T-Plant, S-Plant (REDOX), and U-Plant (Brevick et al. 1997a). Hanford SSTs were connected in series with cascade lines between tanks as a design feature. These cascades allowed solids to settle in the first tank while the more buoyant solids and supernatant were transported to subsequent tanks as the initial tanks became full. As tank contents were retrieved and transferred, multiple waste types mixed. These mixtures do not necessarily maintain the characteristics of the individual waste types. Chemical reactions, which occur as the waste mixes, establish a new equilibrium that invalidates the original waste type labeling (Meacham et al. 2012).

Additionally, the tanks received multiple waste streams and underwent various waste management processes (i.e., sluicing, transfers, material recovery, evaporation, etc.; Agnew 1997), making it difficult to predict current inventory from historical flow sheets without updated sampling and analysis.

The waste phases present in the Hanford tank farms include the following (Peterson et al. 2018):

- **Saltcake** is a mixture of mostly water-soluble solids and “interstitial liquid” occupying the pores in between the particles of the salt matrix. The interstitial liquid usually has the same composition as the supernate. Sodium nitrate is the most common solid phase, though the mineralogy varies significantly among tanks. Other common solids include sodium carbonate (trona), sodium phosphate, sodium fluoride (phosphate natrophosphate), sodium oxalate, and other sodium salts. Potassium salts can be present, but at much lower concentrations. Saltcake also contained entrained water insoluble solids, predominantly aluminum and chromium phases. Saltcake samples are obtained by core sampling.
- **Supernate** (or supernatant liquor) is the aqueous liquid phase that typically resides atop the sludge or saltcake and is usually retrieved from the tank via “grab samples” (i.e., lowering a glass bottle into the supernate layer, remotely removing the stopper from the bottle, and then retrieving the full bottle). Typical supernate is a concentrated aqueous solution of (primarily) sodium salts, including sodium nitrate, nitrite, hydroxide, aluminate, carbonate, phosphate, sulfate, fluoride, oxalate, and others. An average total sodium concentration is about 11 mol/L with an average density around 1.4 g/mL and pH > 12.
- **Sludge** is a mixture of water-insoluble solids and interstitial liquid. The insoluble solids were formed initially in the processing plants by neutralization of the acidic processing solutions containing mixed metal nitrates. Sludge samples are obtained by core sampling. The solids are largely amorphous agglomerates containing oxides/hydroxides of aluminum, iron, silicon, bismuth, chromium, and other metals. Crystalline phases have been identified, including gibbsite [$Al(OH)_3$], boehmite [γ -AlOOH], dawsonite [$NaAl\text{-}CO_3(OH)_2$], cancrinite $Na_3CaAl_3Si_3O_{12}CO_3$], thermonatrite [$Na_2CO_3 \cdot H2O$], natrophosphate [$Na_7F(PO_4)_2 \cdot {}_{19}H_2O$], hematite [$Fe_2O_3$], and clarkeite [Na((UO$_2$)O(OH))(H2O)0-1].

Although early chemical separations and waste management processes in 200E and 200W were alike, the evolution of the plutonium production mission and diminished interaction between the two chemical processing areas resulted in distinctly different wastes being generated at Hanford as a function of location. Figure 3 (adapted from Marcial 2024) illustrates the Hanford production and waste management facilities and their relationships in 200W. These differences could make data on tank wastes sampled and characterized in 200E less useful for technical decisions related to 200W tank waste. Additionally, as part of this literature review, archive samples for analysis from 200W were identified that can address data gaps relevant to WARM tank retrieval and processing. These recommendations align with the findings in Assmussen et al. (2025).

2.0 200W Separation Facilities

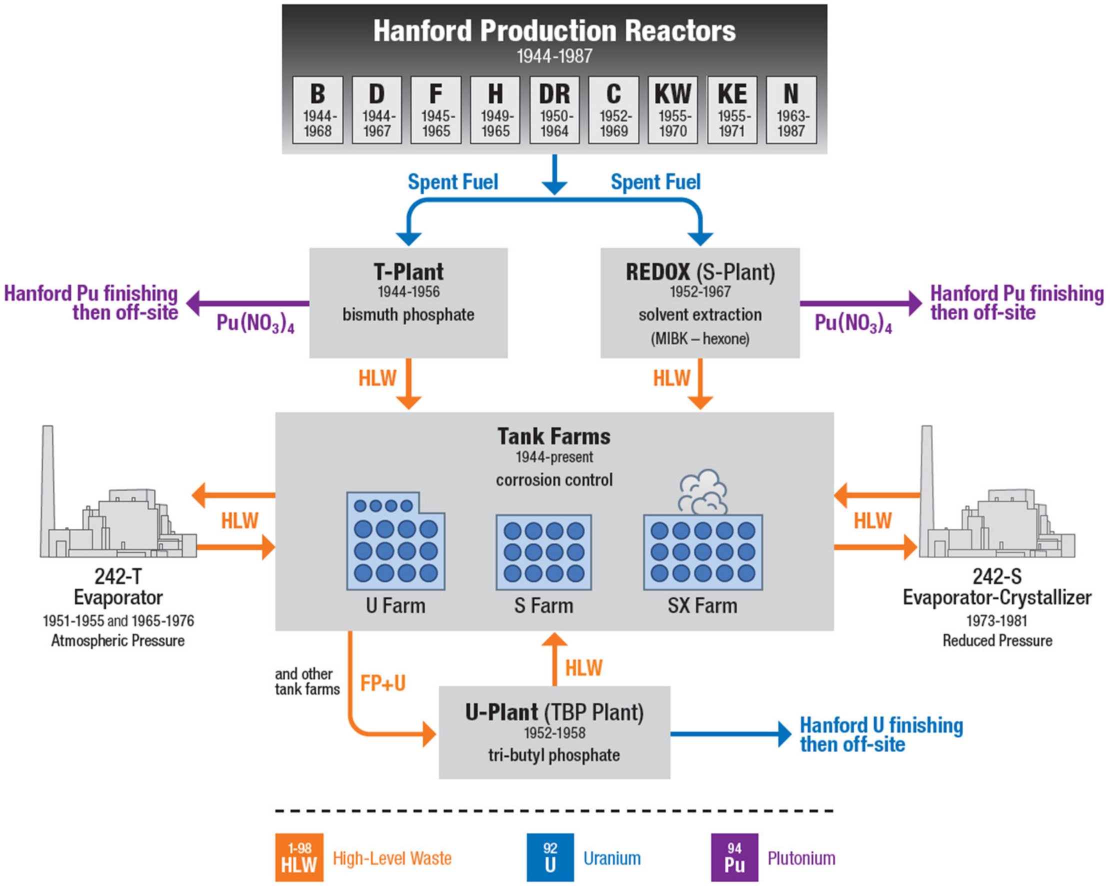

Figure 3. Summary of main chemical separation and waste management processes contributing to 200W tank wastes. FP denotes fission products and MIBK denotes methyl isobutyl ketone.

2.1 S-Plant (REDOX plant)

The REDOX plant (i.e., S-Plant) began processing in 1952 (Anderson 1990) and continued until 1967 (Rockwell 1985). S-Plant carried out the first process to recover both Pu and U, using a continuous solvent extraction process with methyl isobutyl ketone (hexone). The REDOX process, unlike other aqueous-based fuel reprocessing schemes, was operated at a very low HNO_3 concentration because of the acid-instability of the methyl isobutyl ketone solvent. This low-acid flowsheet had two major consequences. First, it was necessary to maintain an excess of $Na_2Cr_2O_7$ through most of the process to keep the Pu in the +6-oxidation state. Reduction of Pu to +4 under low acid conditions would have led to the formation of an unextractable Pu(IV) polymeric species. Second, large amounts of $Al\text{-}(NO_3)_3$ were required as source of nitrate to promote extraction of U and Pu into the organic phase. Consequently, REDOX process wastes are high in Cr and Al (Peterson et al. 2018). The slightly acidic waste stream contained the fission products and large quantities of aluminum nitrate used for Pu/U extraction. REDOX waste was higher in fission product content and lower in volume than waste produced by the bismuth phosphate process (BiPP). Tanks were often self-boiling as a result, impacting the physical and chemical behavior of the wastes, particularly waste rich in aluminum. This waste was neutralized and stored in the 200W SSTs (Wilson and Reep 1991).

2.2 T-Plant

T-Plant was the first full-scale separations plant at the Hanford Site and employed BiPP (like the process run at B-Plant in 200E). BiPP exploits the fact that actinides in the +4 oxidation state preferentially partition from solution into a $BiPO_4$ precipitate, whereas actinides in the +5 and +6 oxidation states remain in solution. This method was used to separate Pu from U, other transuranium elements (i.e., Np and Am), and fission product elements by shuttling the Pu between the +4 and +6 oxidation states (Peterson et al. 2018). The major metallic elements entering the waste were Al, Bi, Fe, Ce, Cr, K, La, Mn, Na, Si, and Zr. Anionic species included nitrate, nitrite, fluoride, phosphate, sulfate, and hydroxide (Peterson et al. 2018).

T-Plant began operating in 1944 (Rockwell 1985) as a separations plant and continued until March 1956 (Gerber 1993). The resulting U-containing waste was neutralized to an alkaline pH and stored in SSTs. Other acid waste (which included most of the fission products) generated by this process was neutralized and stored in separate SSTs (Wilson and Reep 1991). T-Plant scavenged Cs-137 from tank wastes using ferrocyanide, which accounts for 10% of the ferrocyanide waste at Hanford (Hallen et al. 1992).

After ceasing reprocessing activities, T-Plant was repurposed in 1957 as a central decontamination facility for Hanford for the next three decades (Rockwell 1985). These decontamination processes used a myriad of chemicals, including:

- Steam
- Sand
- Chemicals
- Detergents
- Strong nitric acid flush
- A caustic wash with sodium hydroxide combined with sodium phosphate, boric acid, versene, sodium dichromate, sodium tartrate, or sodium citrate
- Oxalic acid
- Phosphates
- Nitric acid
- Ferrous ammonium sulfate combinations
- Potassium permanganate
- Sodium bisulfate
- 1,1,1 trichloroethane or perchloroethylene
- Chloride-based detergents

These various streams, termed “decontamination waste,” were sent to SSTs in 200W and became part of the evaporator feeds and waste concentrates returned to the tanks (Agnew 1997). T-Plant was modified again in 1978 to store fuel assemblies from pressurized water reactors (Rockwell 1985).

2.3 U-Plant (221-U)

U-Plant (221-U) was one of three original BiPP facilities at Hanford, but it was not used for that purpose. The uranium recovery process implemented in the 1950s had three primary functions: (1) recovery of the U-bearing waste from the storage tanks, (2) separation of U from the waste, and (3) conversion of the separated U to UO_3. The U recovered from the waste tanks as well the U produced in the REDOX process were used as feed for the UO_3 plant (Peterson et al. 2018).

U-Plant was modified extensively and used for the uranium recovery processes, operating from 1952 to 1958. The uranium in the SSTs from the BiPP was sluiced, dissolved in nitric acid, and processed through solvent extraction using tributyl phosphate in kerosene to recover the uranium. The resulting acid waste was neutralized (alkaline) and returned to SSTs. The tributyl phosphate waste was treated with potassium ferrocyanide as a cesium and strontium scavenger and generated ~70% of the ferrocyanide waste in the Hanford tank farms. The recovery process resulted in an increase in nonradioactive salts and a small increase in waste volume (Wilson and Reep 1991).

2.4 224-U Building

The 224-U Building was converted to a uranium trioxide (UO_3) plant that began operating in 1952. The UO_3 plant could convert the liquid uranyl nitrate hexahydrate stream from REDOX, U-Plant, and PUREX to a stable, orange-yellow powder. U-bearing waste in the underground storage tanks was mixed with the alkaline supernatant liquid to form a slurry. The slurry was pumped into an underground vault and then fed into a tank containing HNO_3. The acidified waste containing solubilized U was then pumped to the Hanford TBP Plant (221-U Building) for processing. The resulting high-activity waste stream was neutralized, concentrated by evaporation, and returned to the underground waste storage tanks (Peterson et al. 2018). This powder was the base material needed to manufacture uranium hexafluoride (UF_6), the primary feed material for gaseous diffusion plants in the United States. The UO_3 plant was shut down in 1972 but restarted in 1984 and ran until 1993 (Gerber 1996).

2.5 242-S Evaporator

The 242-S Evaporator-Crystallizer was designed to boil off water from waste in an enclosed vessel at reduced pressure, like the 242-A Evaporator-Crystallizer in 200E. The evaporation continued until a slurry containing about 30 wt% solids was formed and returned to the SSTs. The principal products of waste solidification were large volumes of sodium nitrate saltcakes and waste liquors rich in sodium hydroxide and sodium aluminate (Wilson and Reep 1991). The evaporator began operating in 1973 (Anderson 1990) and was shut down in 1981 (Gerber 1993).

2.6 242-T Evaporator

The 242-T Evaporator, like the 242-B Evaporator in 200E, began operating in 1951 (Gerber 1992) to reclaim nonboiling waste storage capacity in existing 200W tanks. The evaporator was shut down in the summer of 1955, then restarted in 1965 and operated until 1976 (Anderson 1990).

The 242-T Evaporator concentrated nonboiling waste in the 200W tanks from the early 1950s until 1955. Many of these same tanks were used in the 1970s as slurry receivers for the 242-S Evaporator. The 242-S Evaporator was more efficient at reducing waste volume than the 242-B and 242-T evaporators and created a more concentrated product. A significant source of uncertainty with respect to 200W wastes is that the wide-ranging feed sources, feed source conditions, and proportions of the wastes processed through individual evaporator campaigns (both 242-T and 242-S) do not allow for confident predictions of concentrated waste composition and physical behavior. The level of resolution of saltcake concentrate composition estimates in Agnew (1997) are at the quarterly level which can obscure specific compositional and behavioral differences as wastes are blended, evaporated, and returned to the tanks. The

S, SX, and U farms contain more than 26,000 kL of saltcake wastes[1]. However, there are very little physical and chemical data relevant to the retrieval, treatment, and disposition of waste in these tanks.

2.7 241-S Tank Farm

The 241-S Tank Farm (S farm) is located in the southwest quadrant of 200W. The S farm contains twelve 100-series, dish bottom design SSTs built in 1950 and 1951. The 100-series tanks are 75 ft in diameter with an operating capacity of 758,000 gal. The tanks were designed to store non-boiling waste at a fluid temperature of 220°F (Figure 4, left). The tanks were constructed at different elevations with connecting overflow lines that allowed waste to cascade from tank to tank. The S farm has four cascades of three tanks each: (1) tank 241-S-101 to -102 to -103, (2) tank 241-S-104 to -105 to -106, (3) tank 241-S-107 to -108 to -109, and (4) tank 241-S-110 to -111 to -112 (Figure 4, right). See Brevick et al. (1997a) for more information on the design, construction, and waste contents of these tanks.

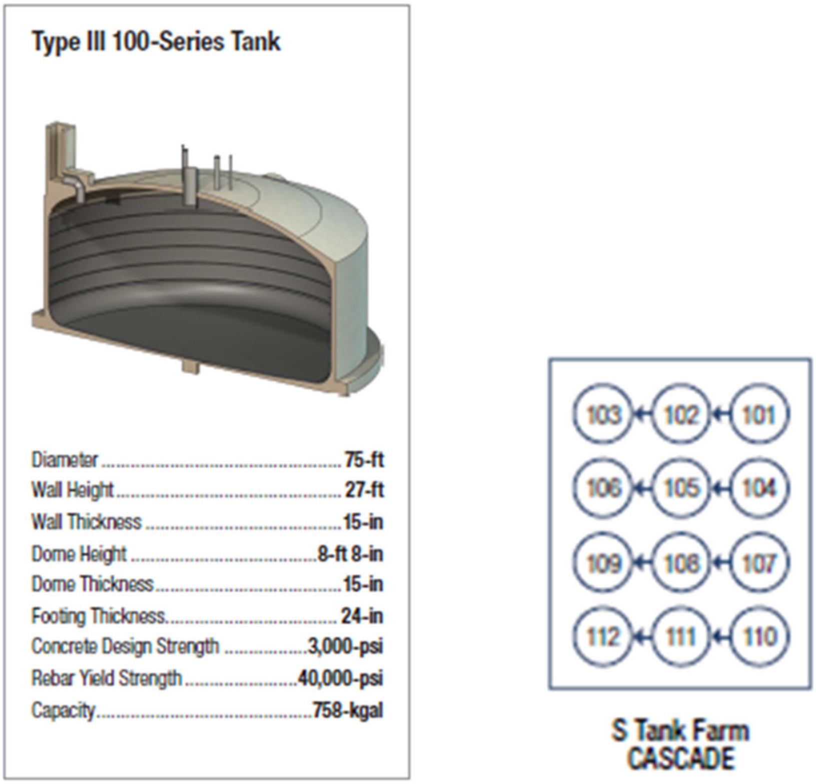

Figure 4. (Left) Type III 100-series tank configuration. (Right) 241-S Farm cascade.

The tanks at S farm were built to store wastes from S-Plant and were also used to store the evaporator bottoms waste from 242-S Evaporator operations. Tank 241-S-102 was also used as a feed tank for the 242-S Evaporator (Agnew 1997). The primary additions to the S farm tanks were REDOX waste (R1), REDOX cladding waste (CWR1, CWR2), water (WTR), REDOX saltcake (RsltCk), and partial neutralization feed (NIT) in transfer waste (Agnew 1997). In 1953, surface condensers were installed to concentrate the waste in the first two cascades. The vapor

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[1] https://twins.hanford.gov/twinsdata/home

condensate from the surface condensers was disposed of to cribs. Tank 241-S-103 served as the emergency dump tank for the 242-S Evaporator and as a receiver for the 242-S cell sump drainage (Leach and Stahl 1993). The S farm tanks were saltwell pumped to remove supernatant liquid between 1984 and 2005. These liquids were transferred to the 241-SY Tank Farm (Swaney 2005). Figure 5 shows the estimated sample data coverage from contemporary laboratory analyses and calculated values (green) against the process engineering or flowsheet estimates with no direct sample data for inventory (blue) in the S farm.

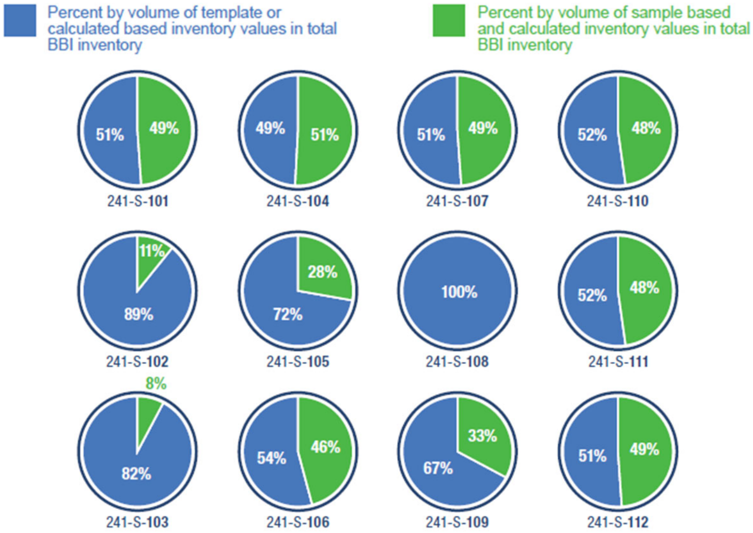


Figure 5. 241-S Tank Farm sample-based inventory data coverage.

2.8 241-SX Tank Farm

The 241-SX Tank Farm (SX farm) contains fifteen 100-series, dished bottom design SSTs built in 1953 and 1954. The 100-series tanks are 75 ft in diameter with an operating capacity of 1,000,000 gal (Figure 6, left). The tanks were designed to store boiling waste. The tank contents were allowed to boil for 1 to 5 years at a fluid temperature up to 250°F. The tanks were constructed at different elevations with connecting overflow lines that allowed waste to cascade from tank to tank. The SX farm has five cascades of three tanks each: (1) tank 241-SX-101 to -102 to -103, (2) tank 241-SX-104 to -105 to -106, (3) tank 241-SX-107 to -108 to -109, (4) tank 241-SX-110 to -111 to -112, and (5) tank 241-SX-113 to -114 to -115 (Figure 6, right). See Brevick et al. (1997a) for more information on the design, construction, and waste contents of these tanks.

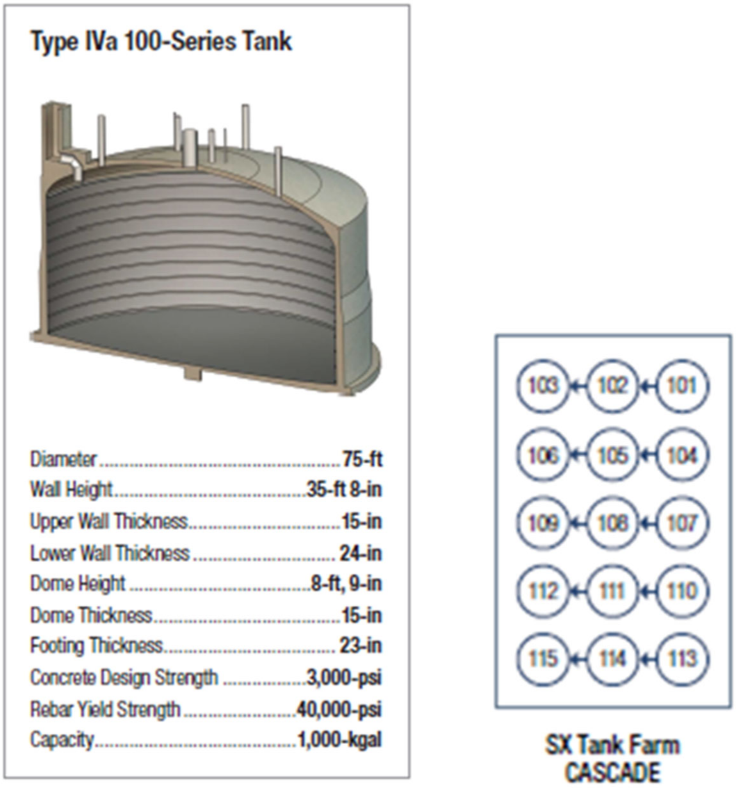


Figure 6. (Left) Type IV 100-series tank configuration. (Right) 241-SX Farm cascade.

The SX farm tanks were the first designed to store self-boiling wastes. Tanks 241-SX-101 through -106 started operations in 1954 and began receiving REDOX (S-Plant) salt waste and first-cycle condensate from S-Plant. The other nine tanks (241-SX-107 through -115) were released to operations at various times from late 1955, when they began receiving REDOX boiling waste and salt waste (Anderson 1990; Leach and Stahl 1993). The primary additions to the tanks were REDOX waste (R1 and R2), REDOX cladding waste (CWR1), REDOX saltcake (RsltCk), partial neutralization feed (NIT), and water (WTR) (Agnew 1997).

Non-process waste added to these tanks includes:

- Concrete or diatomaceous earth (DE). Sample data from 241-SX-113 suggest that DE is present in that tank in significant quantities (Spencer et al. 1998).
- Tank 241-SX-107 contains 41 small bottles of neutralized waste from 100-F reactor, each bottle with less than 1 g of Pu-239.
- Tank 241-SX-110 contains 16 bottles totaling 204 g of Pu-239 and 6 g of enriched uranium (Leach and Stahl 1993).

Figure 7 displays the estimated sample data coverage from contemporary laboratory analyses and calculated values (green) against process engineering or flowsheet estimates with no direct sample data (blue) for inventory in the SX farm.

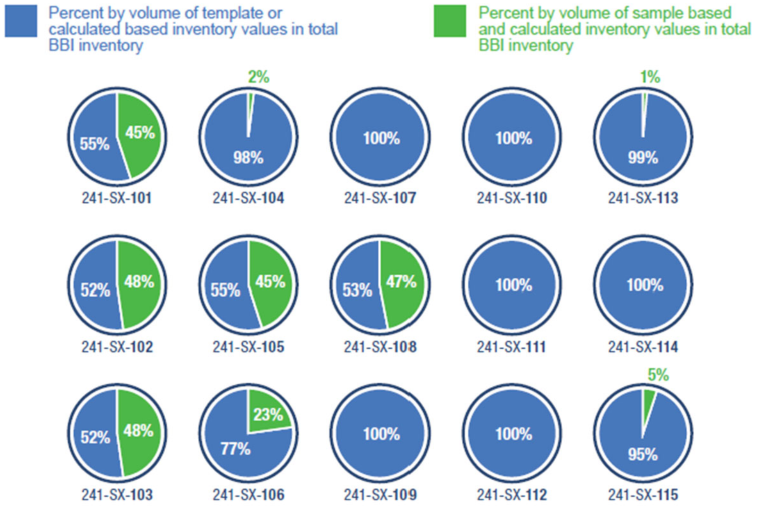


Figure 7. 241-SX Tank Farm sample-based inventory data coverage.

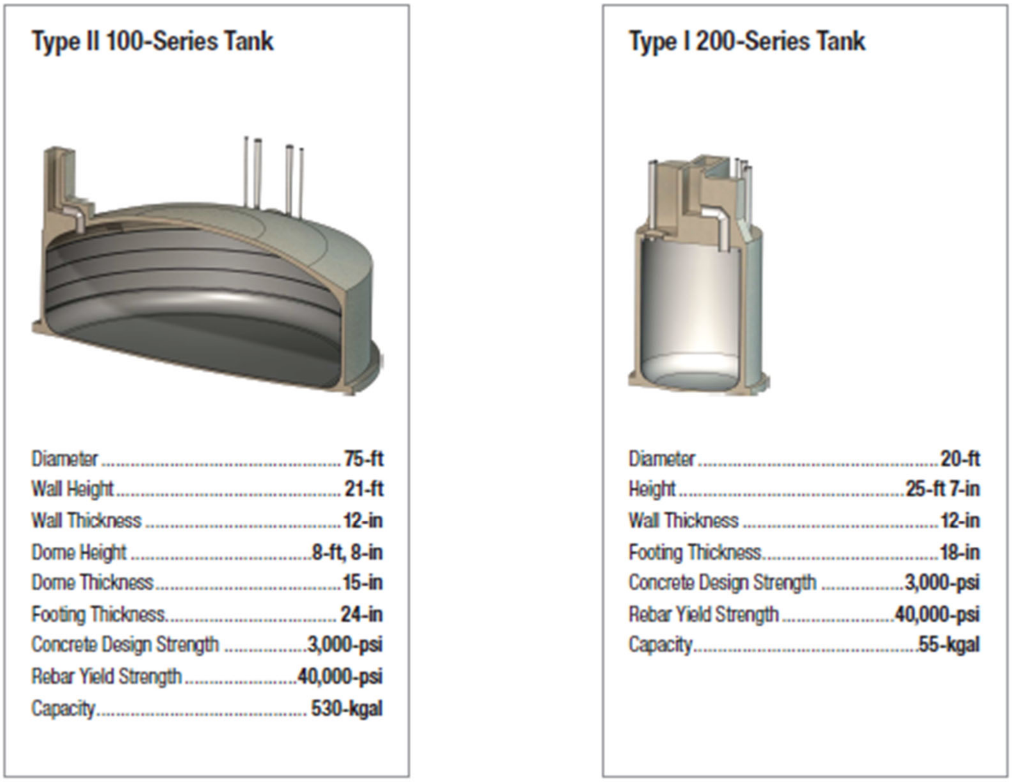
2.9 241-U Tank Farm

The 241-U Tank Farm (U farm) contains twelve Type II and four Type I tanks (Figure 8). The U farm was one of the first four tank farms constructed between 1943 and 1944. The Type II tanks have a 12-in. dished bottom, a 4-ft radius knuckle, a 75-ft diameter, 530,000-gal volume, and an 18-ft 8-in. operating depth. The Type I tanks have a 6-in. dish bottom, a 3-ft radius knuckle, a 20-ft diameter, a 55,000-gal volume, and an 18-ft 8-in. operating depth. The tanks were designed with a primary steel liner and a concrete dome with risers (Brevick et al. 1997a).

The tanks are covered with approximately 7 ft of overburden. Various coatings and materials were used to seal the inside and outside of the tanks, liners, domes, risers, and manholes. Cascade overflows are connected from tank 241-U-101 to -102 to -103, tank 241-U-104 to -105 to -106, tank 241-U-107 to -108 to -109, and tank 241-U-110 to -111 to -112 (Figure 9). Tanks 241-U-201 through -204 were connected to each cascade via a junction box. The tanks in each cascade are separated by 1 vertical foot. The tanks were designed to withstand pH values of 8 to 10 and fluid temperatures no greater than 220°F. The tanks were not designed to contain boiling wastes.

Non-process waste added to tank U-101 includes N-Reactor waste, K-Reactor waste, and 300 Area wastes (Krieg et al. 1990):

- 4.5% enriched uranium N-Reactor fuel elements
- Two cask loads of various solid wastes from 100-K and five cask loads of waste from the 300 Area
- Shroud tubes containing significant levels of ^{60}Co
- 2 gallons of ceramic balls containing samarium used as a poison backup for the reactor control rods
- An estimated 100 ft^3 of sand for shielding added after the addition of the ^{60}Co waste



Type II 100-Series Tank

Diameter	75-ft
Wall Height	21-ft
Wall Thickness	12-in
Dome Height	8-ft, 8-in
Dome Thickness	15-in
Footing Thickness	24-in
Concrete Design Strength	3,000-psi
Rebar Yield Strength	40,000-psi
Capacity	530-kgal

Type I 200-Series Tank

Diameter	20-ft
Height	25-ft 7-in
Wall Thickness	12-in
Footing Thickness	18-in
Concrete Design Strength	3,000-psi
Rebar Yield Strength	40,000-psi
Capacity	55-kgal

Figure 8. Type II 100-series (left) and Type I 200-series (right) tank configurations.

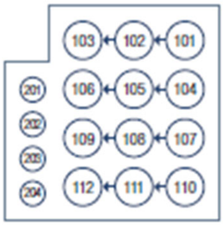


Figure 9. 241-U Tank Farm cascade.

The 16 tanks in the U farm were built in 1943 and 1944. Tanks 241-U-101 through -109 received metal waste from T-Plant and were subsequently sluiced for uranium recovery and scavenged to allow soil discharge (“cribbing”) of supernatant liquids, reclaiming tank space for waste storage. From 1969 to 1971, tank 241-U-101 received a variety of solid waste items, including six cask loads of experimental fuel elements, shroud tubes and samarium “poison” ceramic balls, 1,530 g of 4.5% enriched uranium and 6 g of plutonium, 180 Ci of ^{60}Co and 130 Ci of mixed fission products, and cobalt slugs with 70 Ci of ^{60}Co (Krieg et al. 1990). Tanks 241-U-110 through -112 received first-cycle decontamination waste (1C).

Tanks 241-U-110 through -112 were also used for REDOX waste storage and 242-T Evaporator feed. The four 55,000-gal tanks received cladding waste (CWR1) and waste from REDOX (R1). In the early 1950s, the tanks were filled with liquid that was pumped out in 1977. The tanks currently contain a small quantity of REDOX solids (Johnson 2003). They have been removed from service and are interim stabilized and partially isolated (Brevick et al. 1994). Figure 10 displays the estimated sample data coverage from contemporary laboratory analyses and calculated values (green) against process engineering or flowsheet estimates with no direct sample data (blue) for inventory in the U farm.

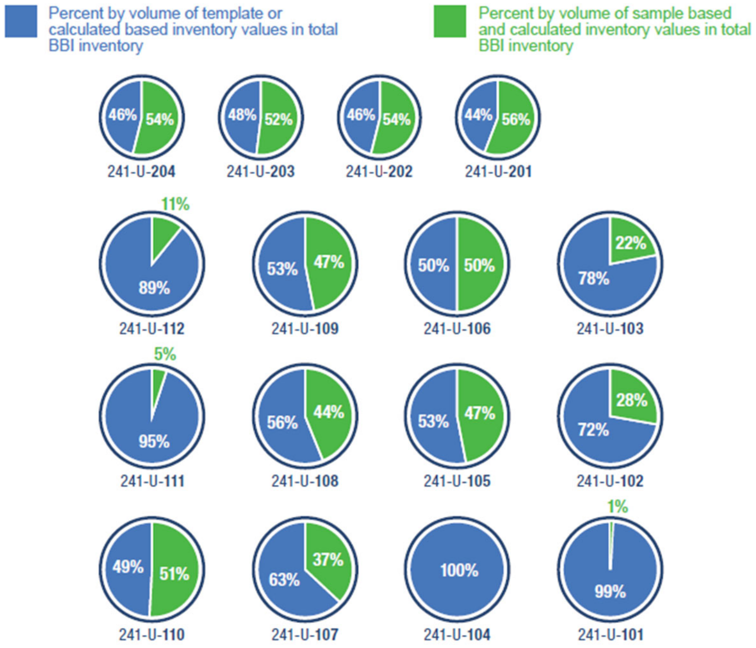


Figure 10. 241-U Tank Farm sample-based inventory data coverage.

2.10 241-SY Tank Farm

The 241-SY Tank Farm (SY farm) was built between 1974 and 1976. The SY farm consists of three 4,391-kL (1,160-kgal) tanks and is the only DST farm in 200W. The SY farm contains three flat bottom DSTs built between 1974 and 1976 (Brevick et al. 1997b). Insulating refractory has been placed between the primary and secondary steel liners at the tank bottom. The SY farm does not use a cascade system between tanks (Figure 11). The tanks were designed for a maximum waste temperature of 250°F (Leach and Stahl 1993). The dome of each tank is penetrated by risers with diameters from 4 to 42 in. (Detrich 2019a; Figure 12 provides a summary diagram of SY farm tank configuration). Figure 13 provides a map-based view of the West Area Tank Treatment (WATT) tank farm locations and the spatial relationships between them. Because these tanks are active and are part of the proposed processing scheme, their contents change and are monitored as part of tank farm operations.

Figure 11. 241-SY Tank Farm plan.

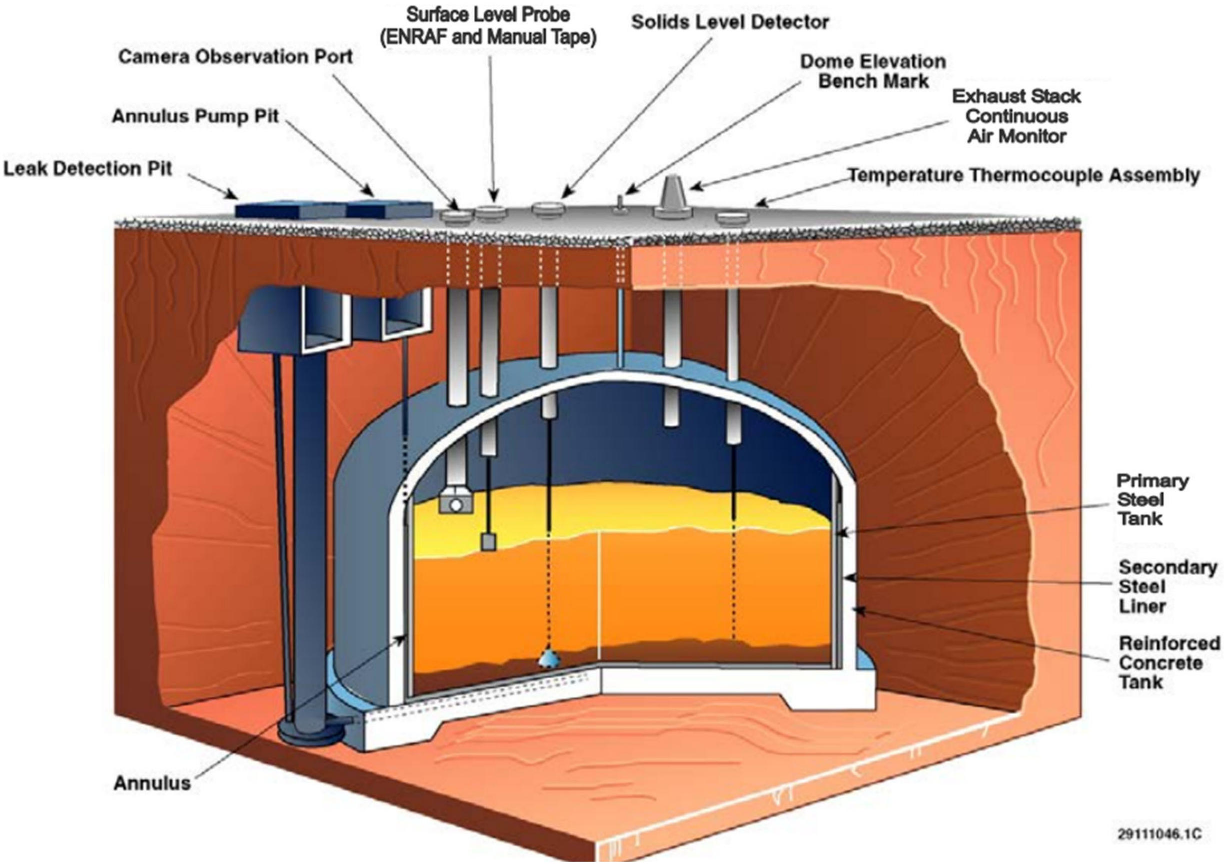


Figure 12. 241-SY Farm tank.

2.11 200W Tank Farms

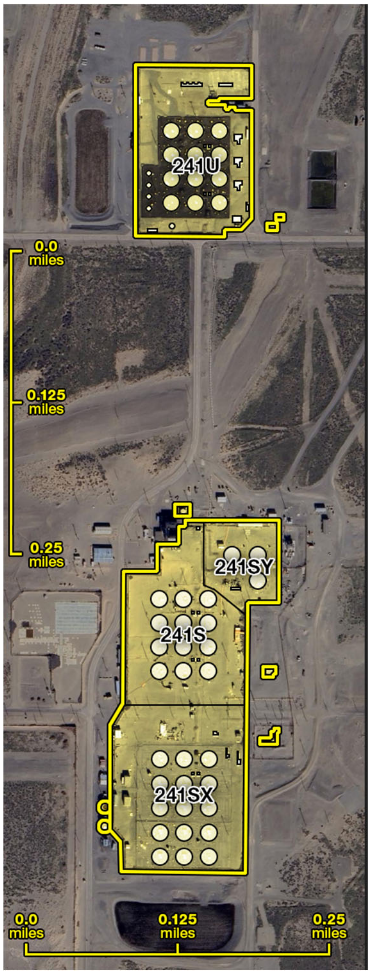


Figure 13. West Area Tank Treatment (WATT) tank farms locations

3.0 Data Needs for the West Area Tank Treatment Alternative

In the 1990s, a significant amount of work was performed to characterize waste from 200E and 200W tanks. Much of this work focused on chemical characterization of core segments and the development of the enhanced sludge washing process that was planned at that time. Subsequent work in the late 2000s assessed some of the physical performance of 200W sludge, but this time for the design of the WTP Pretreatment Facility. The objective of this review is to identify gaps in the existing characterization data and determine how those gaps might be filled for WATT.

Unresolved questions on 200W tank waste that impact the implementation of WATT include (but are not limited to) the expected range of Al solubility under retrieval conditions (frequency of gibbsite, boehmite, aluminate, and other Al phases that have been observed), the potential effect of stabilization on waste condition (Beck 1999), and the presence, magnitude, and particle size profile of insoluble phases as part of the larger volume of saltcake waste in S, SX, and U farms. There is historical characterization information that can be evaluated to anticipate these risks, select preferred archive samples, and designed experimental protocols to effectively address these issues.

3.1 Objectives of the Review

Reports for a limited number of tank samples from 200W in the last 30+ years provide the basis for most of the fundamental technical information on the behavior of these materials (from analytical laboratory testing and process engineering models). Additionally, there are sample data and experimental results from 200E tanks that may also be relevant to 200W tank retrieval, treatment, and disposal. However, the technical scope and implementation of the proposed retrieval and treatment of the wastes in these tanks has shifted considerably over this period, and there is a need to confirm the applicability of these legacy test results and models for detailed engineering design, procurement, construction, and operations in 200W. Alternately, if the data are sufficiently sparse, biased, or unsuited to the current WATT mission, there are archived tank waste materials that could be tested and data that could be obtained in the context of the latest retrieval and treatment processes.

3.2 Method

To support current planning for 200W retrievals, a literature search was conducted to identify the physical properties data available for the S, SX, and U farms. The search encompassed mostly documents from the early 1990s to the late 2010s (~90+ documents, a majority dating from 1995-2012), with a few from the late 2010s to mid-2020s. A few pre-1990 operations documents were also reviewed for relevance and to provide context. The search also identified several journal articles that use existing technical reports, sample data, and modeling outputs in concert with results from the broader technical literature to address key physical properties relevant to tank waste processing.

The literature search focused on 200W waste solid types and their associated physical properties data, including but not limited to solids settling rates, settled density, solids composition, and dissolution characteristics. Rheology, viscosity, particle density, and mineral characteristics are also key data for understanding retrieval, treatment, and disposition of tank waste in the target farms. As part of the literature review, inspection of the narratives provided methods to:

- Identify gaps in the data coverage for the target group of tanks (S/SX/U farms).
- Identify discrepancies or evolutions in qualitative or quantitative results from legacy reports to currently accepted bases.
- Provide context on historical operations in interpreting laboratory results.

4.0 Early Tank Farm Data: Production Operations and Chemical Characterization (1960s to 1980s, contractor laboratory reports/memos/engineering analyses)

These sources are often unavailable to the larger technical community except where they provided data to a journal article or as a reference to an external report. Typical products include interoffice memos and letter reports (reproductions of documents with photos and graphics are often of low image quality and can be difficult to read). However, they did inform later technical scope and research direction at Hanford. Some of this institutional knowledge is available from senior staff researchers and engineering management at Hanford and Pacific Northwest National Laboratory (PNNL), but subject matter expertise is increasingly perishable, as knowledgeable staff are coming to the end of their careers and there are few mid-career technical staff with direct experience testing tank wastes.

These documents sometimes capture insightful qualitative information and subject matter expert judgment regarding specific process engineering topics such as boiling tank waste behavior (Godfrey and Schmidt 1969; Mercier et al. 1981). Other observations regarding sample behavior during transport, preparation, and analysis often provide insight on physical properties that was not part of the analytical plan (Horton 1978) or physical and chemical properties of staged wastes to be concentrated through an evaporator (Puryear 1971). However, it is challenging to extract data patterns or features regularly attributable to tank waste because of changes in tank composition during operations and varying analytical requirements for sample testing. Often, the results are obtained from a single waste sample (or a series of discrete samples), without replication. The degree of technical coverage varies, but there are data for most tanks. Physical properties data remain scarce, but rudimentary composition, solubility, and density data are common.

5.0 Start of Environmental Management Efforts at Hanford and Exploration of Waste Treatment/Disposal Options (1990s to early 2000s)

Background technical information from the production era was consolidated in internal “process aids” document portfolios organized by tank. The early tank characterization efforts used and leveraged this historical information as part of the research narrative using these references to synthesize a holistic view of the data and process knowledge around the waste in a tank. Typical products include contractor-produced tank characterization reports, contractor and PNNL laboratory test reports, and technical reports from other DOE national laboratories.

A significant feature related to sample acquisition captured as part of the characterization sampling record is that the percent recovery of solid segments is often irregular (Brown 1993; DiCenso et al. 1994; Baldwin 1996; Simpson 1996; Jo 1996; Bell 1997; Field 1996; Field 1998, Brown 1997; Hu 1997; NHC 1999a, 1999b, 1999c, Steen 1999a). Sometimes little or no sample is obtained because of mechanical issues with the sampler; in other cases, sampling is stopped because of downforce issues with the sample rig and the vertical profile of the tank is incomplete. Furthermore, sampling locations are often limited, introducing additional spatial bias into the sample data.

These sampling and analysis efforts aimed to address emerging safety concerns and evaluated preliminary design, delivery, treatment, and disposition of wastes for vitrification. Significant research regarding general saltcake dissolution behavior is captured in Herting and Edmondson 1998; Herting 1999a, 1999b, 2000, 2001a, 2001b, 2002; and LMHC 1999. Other saltcake characterization efforts are documented in Herting et al. 2002; CH2MHILL 2006a, 2006b; Eacker et al. 2006; Cantrell et al. 2008; and Herting et al. 2015.

Specific 200W tank waste dissolution testing can be found in NHC 1999a (SX-104); Person 1999 (U-102 and U-103); Herting 2001b (U-107); Herting and Bechtold 2002 (S-112); Herting 2002 (S-112); Callaway 2003 (S-102); Mahoney and Josephson 2004 (S-112); ORP 2005 (S-102 and S-112); Voogd 2005 (S-112); Parker and Barton 2007 (S-112); Seidel 2010 (SX-105); and Huber et at. 2011 (SX-105).

Early sludge waste processing research is captured in Lumetta et al. 1994, Lumetta and Rapko 1994; Rapko et al. 1995; Temer and Villarreal 1995; Lumetta et al. 1997, 1997a, 1997b; Temer and Villarreal 1997; Lumetta et al. 1998; and Spencer et al. 1998. Specific 200W tank sludge testing can be found in Brooks et al. 1998 (S-107); Hunt et al. 1998 (S-101); Lumetta et al. 2001 (S-110); and Rapko et al. 2002 (S-110). Typically, these experiments were performed at elevated temperatures (sometimes 100°C), often in 3M NaOH, rather than the expected processing environment for 200W tanks retrieval and treatment, estimated to be ambient temperatures where the impact of additional NaOH has not been evaluated. This focus, especially with respect to the impact of caustic leaching pretreatment, represents a substantial bias in physical property measurements because most data were collected from post-pretreated materials (Wells et al. 2007). However, the available water digestion results from both saltcake and sludge characterization could be reviewed and consolidated for use in testing the settling time estimate method proposed by Williams et al. (2024) vs. the method proposed in Camenen (2007).

Physical properties information remains sparse and irregularly collected. Six tanks (S-102, S-104, S-111, S-112, U-103 and U-107) have measured rheological parameters; no tanks in SX farm have measured rheological parameters. Wells et al. (2011) and Golcar and Reynolds (2015) identify the extent of knowledge regarding relevant physical and rheological properties for retrieval, transport, treatment, and disposal, and their associated gaps related to processing through WTP. Much of the data available in Wells et al. (2011) for tanks in S, SX, and U farms were obtained from composite samples that lack the fidelity for understanding waste behavior in the tank-by-tank retrieval scenario envisioned for WATT. Furthermore, data that were collected suffer from a lack of standardized sample treatment and measurement equipment. For example, when controlled for sample handling and instrumentation, data from 19 of 49 tanks with particle size distribution data were selected for inclusion, and only 3 of those tanks were in 200W (S-101, S-107, SX-108; Wells et al. 2007). Similar analytical coverage is seen for other physical and rheological properties in 200W tanks (typically 3 or 4 tanks with laboratory results).

6.0 Focused Sampling and Analysis for Design and Operations of the WTP and Its Associated Infrastructure (mid-2000s to present)

A further bias favoring 200E tanks begins to emerge in sampling to address various requirements for the WTP where technical work was performed in a focused fashion to NQA-1 standards. Typical products are dual-organization (PNNL/WTP) or “One Hanford” contractor technical reports. Specific technical reports addressing waste feed delivery, pretreatment, and WTP engineering design decisions include Wells et al. 2007; Poloski et al. 2007; Fiskum et al. 2008; Shimskey et al. 2009; Snow et al. 2009; Meacham et al. 2012; Wells et al. 2012; Lee et al. 2012; Daniel et al. 2018; Wells and Cooley 2019; and Wells et al. 2020a, 2020b, 2023.

Other reports focused on H_2 generation and preventing buoyant displacement gas release conditions during operations and waste feed delivery (Hedengren et al. 2000; Wells et al. 2000; Stewart and Meyer 2001; Hu 2004; Stewart et al. 2005; Wells et al. 2013; Meacham et al. 2014). Physical properties data from SST wastes remain scarce; there is an emphasis on the use of simulants to quantify these features (Golcar et al. 2000). Additionally, little if any relevant physical properties data are available for tanks in 200W (Wells et al. 2011; Golcar and Reynolds 2015).

7.0 Systematic Review of Hanford Technical Literature (mid-2000s to present)

Some of the peer-reviewed technical literature for Hanford has extensive citations (hundreds of documents) from the academic literature as well as a broad swath of domain-focused Hanford tank waste data (experiments and models). These literature sources are sometimes limited in their use of production and surveillance data obtained during operations and early characterization testing. Contractor-developed technical reports are rigorous but not readily available for peer-review. These reports are not necessarily focused on WTP technical issues but are more general in the scope of their study, such as aluminum solubility (Reynolds 2012) or pre- and post-saltwell pumping impacts (Detrich 2019b).

These documents provide deep technical data analysis and subject matter expert review/synthesis of data collection using tank samples and waste simulants, robust analytical laboratory treatments, and modeling results. However, the content and analysis reflect the technical and engineering choices needed to maintain safe operations in tank farms and operate waste feed delivery to WTP with significant pretreatment. There are some data and analyses relevant to WATT that could be extracted from the following citations; however, these reports do not fulfill the need for defensible, technically robust process knowledge for the selected tanks in 200W. They point toward a need for additional testing from the available sample archive.

- Particle settling and dispersion behavior is discussed in Josephson et al. 2006; Camenen 2007; and Williams et al. 2024.
- Porosity, permeability, and tortuosity of Hanford tank waste (Field and Ogden 2021)
- Solids speciation and mineralogy of various waste solids are provided in Gong et al. 2003; Reynolds et al. 2013; Reynolds et al. 2012; Harrington 2011; Herting and Reynolds 2016; Bolling et al. 2020; and Westesen and Peterson 2022.
- Historical and contemporary systems perspectives of Hanford waste processing are discussed in Peterson et al. 2018; Colburn and Peterson 2021; and Marcial et al. 2024.
- Selected solubility behavior is captured in WRPS 2013 (Al leaching), Toghiana et al. 2005 (Na-F-SO4), Reynolds and Belsher 2017 (Na-F), Britton 2019, Mahoney et al. 2020 (F), and Westesen and Peterson 2022 (Al).

Recent studies reflect the current direction in 200E toward DFLAW and DFHLW processes and no/minimal pretreatment (Marcial et al. 2024). There may be data obtained for vitrification that are relevant and common to the waste processing considered for use at 200W (Wells et al. 2011; Peterson et al. 2018), but there also are significant differences in the technical requirements that may hinder straightforward leveraging of previous data and analysis (e.g., Koopman 2013). Most relevant is the role of 241-SY-103 as the settling tank and the tank's operating limit and waste management options for solids accumulation.

8.0 Results

8.1 Overview

A retrieval sequence for SSTs for alternative waste processing and disposal has been proposed for 200W. Using the literature cited in this report, an assessment was done to determine the anticipated volume of residual solids from each of these retrieval steps. This assessment focused on the inventory of aluminum and to a lesser extent the chromium in each of the WATT tank farms and in the proposed archive sample candidate tanks. In general, sludge samples have been characterized by high aluminum concentrations (and by corollary, very high Al:Cr ratios). Two types of sludges present in west area have been typically found – those high in boehmite (such as REDOX sludges that boiled) and those high in gibbsite (such as REDOX cladding wastes). Samples from salt cake tanks are generally characterized by lower Al:Cr ratios and result in distinctly different dissolution behavior and physical properties.

The details of the assessment for each waste type are discussed in turn. For saltcake samples that had not been previously tested, the results from other West Area saltcakes were used as a stand-in at this time. As can be seen from Table 1, tanks S-110 and S-111 represent the single largest anticipated volumes of insoluble solids for this retrieval. The maximum volume represents the anticipated tank-scale of gravity-settled volume from laboratory-scale testing. Note that these tests resulted in an increase in sludge volume upon water addition from the archive sample dried storage state, suggesting formation of additional solids after exposure to water. The minimum volume represents the volume achieved during centrifugation of these samples that would represent the tank-scaled waste volume under compression.

An additional consideration for sampling these tanks is clarifying the role that S-102 played as the evaporator feed tank and in distributing S1 and S2 saltcake wastes. There may be a layer (or layers) of the less soluble waste phase like that found in S-102 in these tanks (Callaway 2003), or that phase could be dispersed throughout the larger waste volume. Visual inspection of the core segments in S-110 and S-111 shows changes in color, indicating differences in feed blend compositions that were deposited. Furthermore, the heterogeneity indicated from the analytical data as a function of depth suggests that the presence and quantity of insoluble solids can vary considerably within these tanks (Field 1997; Steen 1996,1998a; 1998b, 1999). This feature may be present across several other tanks of interest (S and U farms) because of how the 242-S Evaporator campaigns were staged, and the feed blends are not easily distinguished from the historical record because of the level of resolution of the source data (Agnew 1997).

Because of the degree of uncertainty regarding solubility and other physical properties associated with these wastes and their potential contribution to significant solids formation in tank SY-103, analysis of archive samples is recommended. The next largest grouping of wastes (by volume) are those indicated to have saltcake with a measurable amount of sludge present, represented by tanks S-103, S-108, S-109, and SX-102. These tanks contain mostly saltcake (1,483,000 gal) with 82,000 gal of sludge mixed in. Archive sample analysis of SX-102 can provide relevant comparisons to determine if inclusion of R1 waste impacts the Al solubility of predominantly saltcake wastes, including identifying potential gibbsite formation over time after saltcake redissolution (Lane 1978).

The next largest source of solids (by volume) are the U farm tanks that contain REDOX cladding: U-105, U-107, U-108, and U-109. These tanks received S2 saltcake waste and CWR waste. Archive sample analysis of U-107 and U-108 is recommended to characterize potentially varying Al solubility and improve quantifying insoluble CWR solid settling behaviors.

The fourth largest source of solids (by volume) is associated with tanks that contain nearly exclusively salt: S-105, S-106, SX-106, U-103 and U-106. Archive sample analysis of S-106 is anticipated to provide needed physical properties data for residual solids from saltcake dissolution. Wastes from U-103 were previously observed to have sensitive dependence for phosphate crystallization (Beck 1999).

The fifth largest source by volume are tanks that contain a small quantity of R1 sludge that did not boil: S-102, U-101, and U-102. There are no high-fidelity physical properties-based sample data of non-boiling REDOX wastes; thus, archive sample analysis of tank U-102 is recommended to obtain them. The next source is represented by R2 waste and consists of tank SX-110, with the same rationale as U-102. Wastes from U-103 were also previously observed to have sensitive dependence for phosphate crystallization (Herting 1999b) The final waste type is associated with a mix of 1C bismuth phosphate waste with R1 waste represented by tank U-111. Although 1C sludge data from 200E samples could provide some relevant physical properties data, the introduction of R1 waste may introduce unexpected settling and solubility behavior.

Table 1. Scenario 11[(a)] tanks and estimated tank volumes (anticipated range of residual waste volume, in gallons).

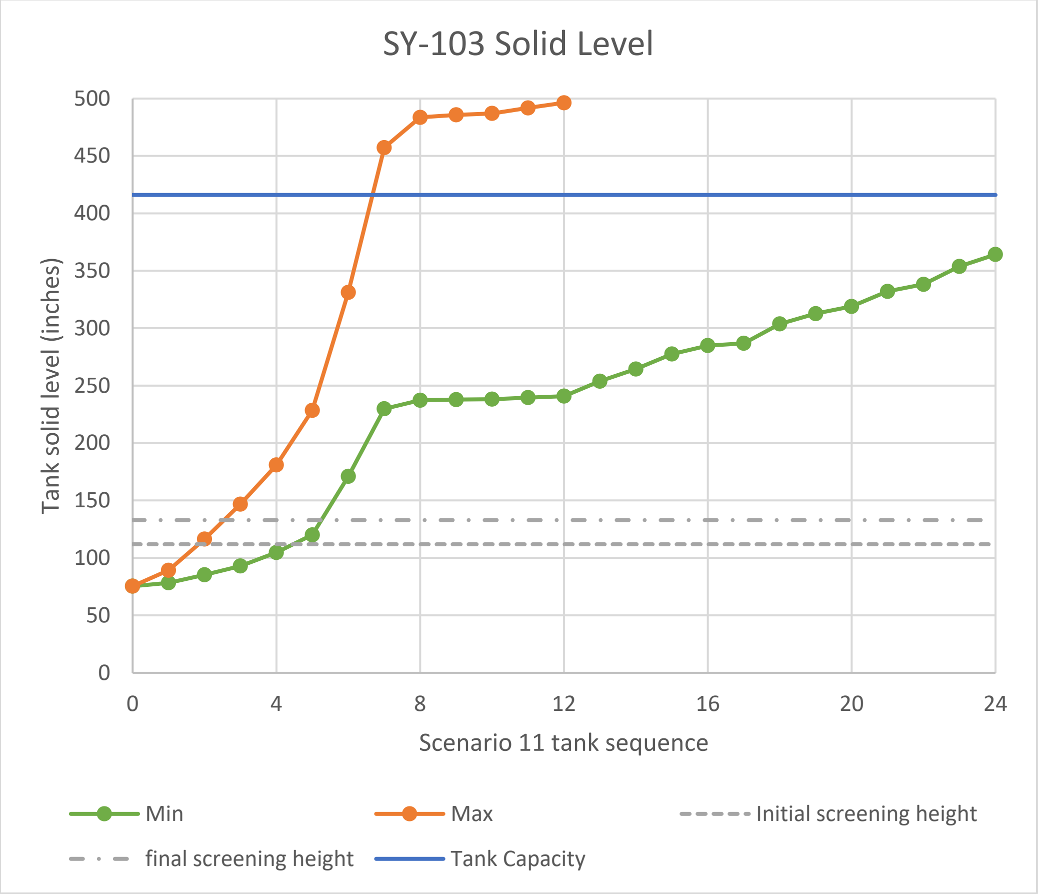
Scenario 11 Tank Sequence	Tank	Estimated Minimum Volume Insoluble Solids (gallons)	Estimated Maximum Volume Insoluble Solids (gallons)	Waste Grouping
1	241-S-105	8,029	38,188	Salt only
2	241-S-109	19,248	74,647	Salt with R1 sludge
3	241-S-103	21,173	83,803	Salt with R1 sludge
4	241-S-106	32,308	93,870	Salt only
5	241-S-108	42,353	131,132	Salt with R1 sludge
6	241-S-111	140,153	282,837	REDOX sludge
7	241-S-110	161,920	346,980	REDOX sludge
8	241-S-102	20,548	72,604	R1 Non-boiling
13	241-U-108	35,883	108,144	REDOX cladding
14	241-U-107	29,008	82,556	REDOX cladding
15	241-U-109	35,912	83,704	REDOX cladding
16	241-U-103	20,388	112,528	Salt only
17	241-U-106	5,403	25,140	Salt only
18	241-U-102	46,460	190,390	R1 Non-boiling
19	241-U-111	24,683	92,701	Bi-phosphate + R1
20	241-U-101	17,363	61,035	R1 Non-boiling
21	241-U-105	36,084	99,326	REDOX cladding
22	241-SX-106	16,765	79,051	Salt only
23	241-SX-110	42,997	154,278	R2
24	241-SX-102	28,661	118,812	Salt with R1 sludge

(a) Scenario 11 is the current baseline sequence for processing the 200W tanks as part of WATT. However, tank processing sequence is subject to change as new information becomes available. The U farm 200-series tanks are not included due their small volume relative to the other SSTs.

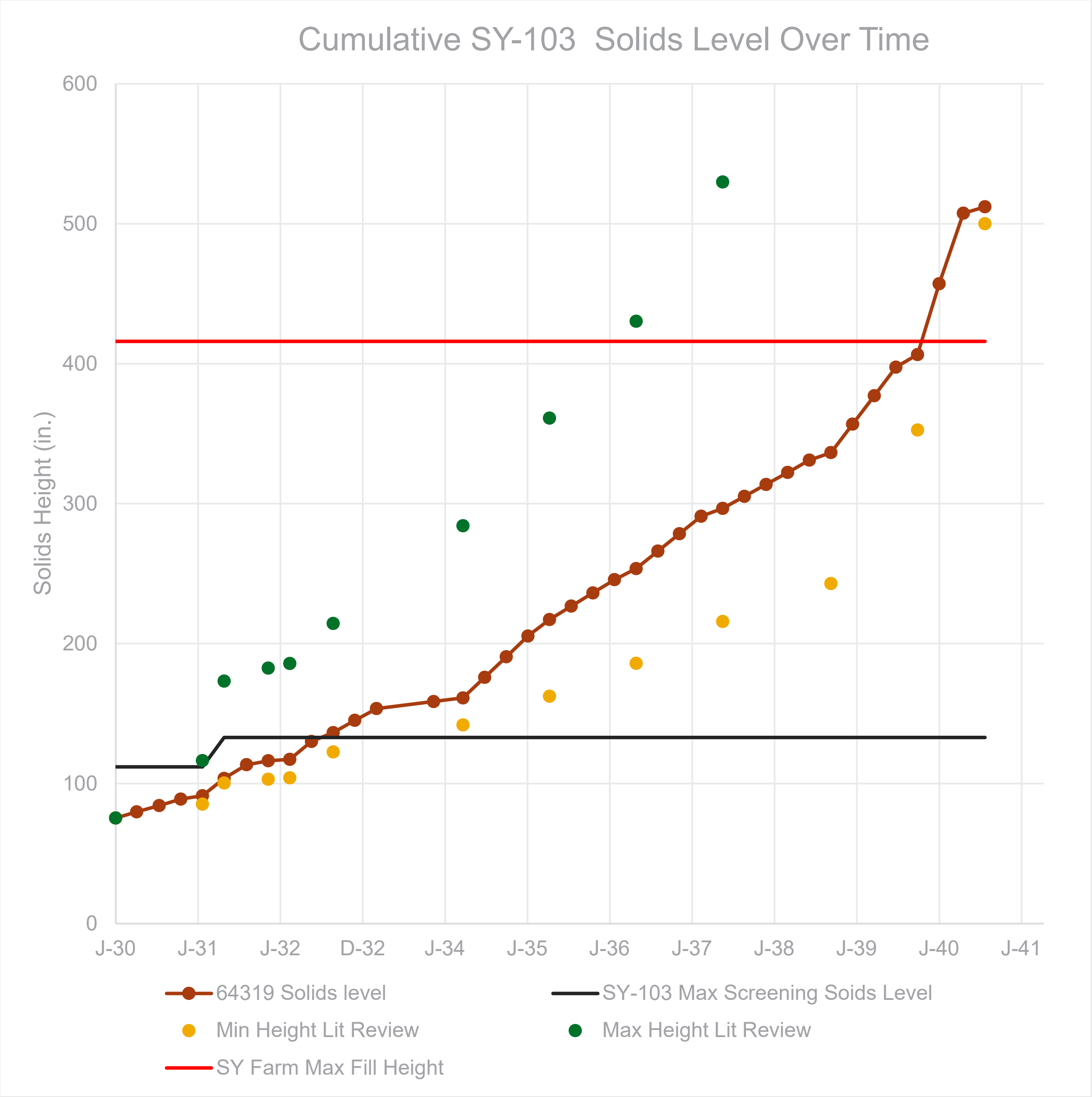
8.2 Projected Solids Accumulation during WATT

The WATT mission will require continued processing of retrieved waste through the SY farm. This processing entails maintaining a feed of retrieved wastes from the SSTs, operational transfers between the SY tanks, operations of the proposed retrieval and processing system, sustained treatment, transportation and offsite disposal capacity, and, most importantly, maintaining operation of the three DSTs at SY farm. The continued accumulation of solids in tank SY-103 will eventually cause the height of the solids layer to exceed the operational height limit. If this height limit is exceeded, no further waste additions to the tank will be permitted until the solids are mitigated to reduce the solids level. According to the analysis of the preliminary WATT flowsheet, the accumulation of solids in SY-103 will exceed the height limit within the first few years of retrievals.

Figure 14a shows an example projection of solids height accumulation in SY-103 from the Scenario 11 preliminary flowsheet using the values in Table 1. Note that there will likely be additional changes to the Scenario before implementation. Figure 13b provides the latest forecast of solids height accumulation using a spreadsheet model that estimates solids using a thermodynamic model and the assessment used in Figure 13a. Note that the sequence of tanks are slightly different between these two assessments; Figure 13a is based on the tank order in Scenario 11, Figure 13b is the time-sequenced order presented in Nguyen 2025 that includes the U-200 tanks . The minimum height estimates from empirical data and the spreadsheet model demonstrate close behavior. However, the empirical data based on the maximum values suggest that the current series of tanks could exceed the SY-103 height limit early in the retrieval campaign and stall progress. The objective of additional testing should be to reduce the uncertainty in this assessment, and in particular provide insight into the fractionation of aluminum and chromium with water addition and to provide information on the effective solids loading that can be achieved from various waste types. The requested archive data are anticipated to narrow the gap between the minimum and maximum empirically derived solids accumulation.



(Figure 13a, Scenario 11)



(Figure 13b, Nguyen 2025)

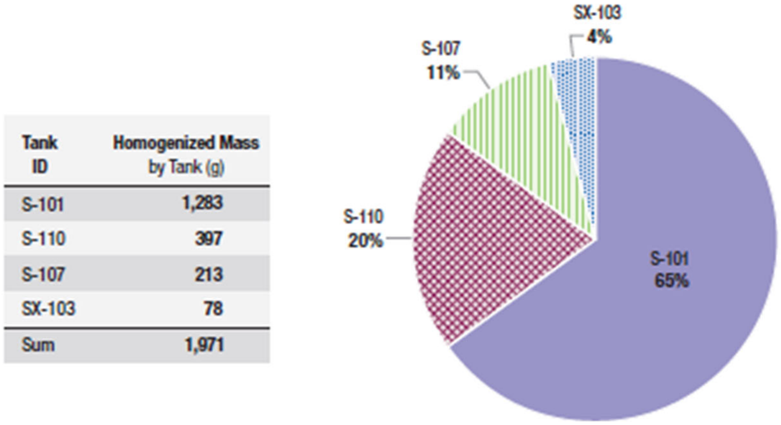
Figure 14. (a) Projected solids accumulation based on laboratory results (low and high estimates based on Fiskum et al., 2008) in tank 241-SY-103 during WATT processing; (b) projected solids accumulation in tank 241-SY-103 based on thermodynamic modeling estimates of solids formed during WATT processing (Nguyen 2025).

8.3 REDOX Sludge

Tanks S-101, S-104, S-107, and S-110 were the lead tanks in their respective cascade. These tanks are indicated to hold the bulk of the sludge solids in S farm (785,000 gal). All these tanks are known to have boiled (Godfrey and Schmidt 1969), providing conditions favorable to boehmite formation. The sludge phase from each of these tanks (and S-111) have been previously studied to assess the fractionation of aluminum and chromium with water addition. Prior testing has demonstrated that the sludge phases of these tanks all contain predominantly aluminum and has either confirmed or implied that the aluminum mineral phase is boehmite. As such, it can be assumed that these four tanks have similar physical properties for settling and rheological behavior. While each of these tanks contains both saltcake and sludge, the volume of solids expected from retrieval of these tanks is dominated by the sludge phase, thus the sludge solids should be the focus of additional assessment.

While tank S-111 was not identified as having boiled, analysis by Lumetta et al. (1997a, 1997c) indicates that boehmite was the predominant water-insoluble form of aluminum from this tank. Samples from S-101 and S-111 were tested using the same protocols. Tests for S-101 and S-111 both indicated roughly 10% of the aluminum was water soluble – further confirming that S-111 is likely to have similar properties as other REDOX sludges. These results suggest that despite the potential differences in process history, S-111 sludge should be expected to behave like the balance of the REDOX sludges in S-101, S-104, and S-110. Table 2 indicates that the compositions of these solids are all relatively consistent, with aluminum as the primary component. All these samples were leached, and those leaching tests indicated that the aluminum was slow to dissolve (implying boehmite as the mineral phase).

Tank S-111 does have slightly different chemical characteristics from the balance of the waste, as it contains significantly less uranium and strontium. For S-110 and S-111, the primary difference between the minimum and maximum volume levels given in Table 1 are associated with the level of consolidation expected. In laboratory-scale testing of REDOX sludge (Fiskum et al. 2008), as-received solids settled to 25 wt% insoluble with a slurry density of 1.26 g/mL. Again, from Fiskum, the centrifuged solids were present at 46 wt% insoluble with a slurry density of 1.37 g/mL. This basis was then corrected using as-received samples from tanks AN-101 and AN-106, which on average reached roughly 90% of the solids loading represented by the centrifuged solids loading. Thus, the primary uncertainty for these two tanks is likely associated with the degree of consolidation. Figure 15 provides the basis for the composite material tested. Note that these settled solids come from a mix of predominantly S-101 (65%) waste, with lesser amounts from S-110 (20%), S-107 (11%), and SX-103 (4%). Note that no settling data is available for this waste type (REDOX sludge) at conditions expected during waste retrievals.



Tank ID	Homogenized Mass by Tank (g)
S-101	1,283
S-110	397
S-107	213
SX-103	78
Sum	1,971

Figure 15. Tank source distribution of REDOX sludge composite.

Since tank S-110 contains the single largest volume of solids expected to be recovered, it is recommended that a sample of this tank be re-evaluated to assess the fraction of aluminum that will dissolve upon water addition as well as the settled solids, centrifuged solids loadings, and settling rate determination at a variety of solids loadings.

Table 2. Compositions of REDOX sludges (selected analytes).

Analyte (µg/g)	S-101	S-104	S-107	S-110	S-111
Al	342,500	150,000	205,000	325,000	160,215
Cr	10,500	3,850	6,030	23,050	3,745
Fe	5,509	3,020	4,890	14,150	45
Mn	6,902	2,090	1,260	5,305	50
Ni	721	306			5
P	763	17	2,040	1,415	2,000
Si	3,500	3,950	7,100	5,500	670
Sr	1,098	651	480	1,240	3
U	21,600	9,360	14,000	23,500	155

Reference: S-101, S-104 S-111: Lumetta et al. 1997a, 1997c; S-107: Lumetta 1997b; S-110: Lumetta et al. 2001

8.4 Saltcake with R1

As shown in Table 3 much of the aluminum in saltcake tanks with R1 is associated with the salt cake that is present. Thus, most of the residual solids after retrieval will likely be from that saltcake. However, numerous species such as gibbsite [$Al(OH)_3$], boehmite [γ -AlOOH], dawsonite [$NaAl\text{-}CO_3(OH)_2$], cancrinite $Na_3CaAl_3Si_3O_{12}CO_3$], thermonatrite [$Na_2CO_3 \cdot H_2O$], natrophosphate [$Na_7F(PO_4)_2 \cdot 19H_2O$], sodium fluoride [NaF], sodium oxalate [$Na_2C_2O_4$], sodium carbonate decahydrate [$Na_2CO_3 \cdot 10H_2O$], sodium fluorosulfate (Na_3FSO_4), burkeite, $Na_6CO_3(SO4)_2$, and $Na_{13}(PO_4)_4(OH) \cdot 48H_2O$ are all potential candidates for wastes where saltcake and R1 waste could be intermingled and result in higher than anticipated solids loadings during retrieval. It is important to try to assess both the potential saltcake and sludge contributions to the solids in SY-103. The ratio of Al present as sludge to the ratio from saltcake varies considerably among these four tanks.

Table 3. Source of Al in saltcake with R1 tanks [Best Basis Inventory (BBI) Al values].

Tank	Sludge Al Inventory (kg)	Saltcake Al Inventory (kg)	Al Mass Ratio (sludge:saltcake)
S-103	10,607	24,195	0.438
S-108	6,288	49,220	0.128
S-109	15,287	9,602	1.592
SX-102	9,145	40,786	0.224
Total Al mass	41,327	123,803	0.334

Source: https://twins.hanford.gov/twinsdata/home

The cores for saltcake samples show an average Al:Cr mass ratio of 3.3 for the bulk sample. This is consistent with the ratio of 3.05 that Fiskum measured for S-saltcake composite. However, many of the segments from tank SX-102 demonstrated significantly higher Al:Cr ratios, indicating more sludge like behavior. While several segments had an Al:Cr ratio near 3, several others had significantly higher ratios, some as high as 25. These results suggest that those segments likely contained sludge with more R1 character. At this time, there are no physical property measurements that can be attributed to R1 waste blended with saltcake. Additional testing is required to assess this waste type, in particular the fractionation of aluminum and chromium with water addition, the settled solids loading, the centrifuged solids loading and the settling rate at various solids loadings.

There were no samples of S-108 identified in the archive. There were only one or two samples each from S-109 and S-103. A total of six samples from SX-102 were identified and contained the highest mass of insoluble solids. Based on the original segment analysis, these samples should represent a ratio of sludge Al to saltcake Al of 0.36 (Steen 1999b). This is slightly higher than the average indicated for SX-102 from the Hanford Site BBI but comparable to the overall average for this waste type. However, this recommended series of archive analyses will provide a reasonable point for comparison with the existing saltcake characterization to determine how to include R1 waste with saltcake and whether it will significantly impact system performance and solids accumulation in SY-103.

8.5 REDOX Cladding

The tanks that contain REDOX cladding hold a mix of saltcake and cladding waste. Table 4 presents a breakdown of aluminum between these two phases for tanks U-105, U-107, U-108, and U-109. It should be noted that according to the BBI values, the aluminum inventory is roughly split between the sludge and saltcake phases. Prior testing of REDOX cladding used sludge samples from U-105 and the U-200 series tanks (Snow et al. 2009). These samples had been identified as sludge samples and were intended only to represent the sludge fraction of this waste type. Testing with this waste type indicated it has significantly different physical properties than the REDOX waste. While the concentrations of aluminum in the washed solids were similar to concentrations in the REDOX waste (297,500 µg/g), the physical properties were dramatically different.

This material settled to 55 wt% insoluble solids with a slurry density of 1.62 g/mL and centrifuged to 57.6 wt% with a slurry density of 1.71 g/mL. This slurry also settled relatively quickly. However, only a single settling data point was obtained because settling was not the primary route intended for solid-liquid separation. The characterization data for the cores from U-108 indicated that the samples were likely saltcake. For U-109, only two segments from core 123 segment 9 indicated high quantities of aluminum that would be associated with sludge. Approximately 180 g of sample from this segment is available for testing. It would be appropriate to test this segment to assess settling behavior over a wider range of conditions.

An assessment of the cores from U-108 (Bell 1997) suggests that the saltcake present in these tanks has a significantly different character than the saltcake in the S and SX farms. Water washing of these solids dissolved nearly all the aluminum present (ranging from 82% to 96%). In contrast, the chromium dissolution with water washing ranged from only 7% to 12%. As such, these solids left over after retrieval of saltcake from the U farm should reasonably be expected to be significantly different in nature than those from the S and SX farms. U-109 demonstrated a similar, although somewhat muted, behavior to U-108, which resulted in significantly higher aluminum solubilization with water addition than was seen for chromium (Baldwin 1996). There are many U-108 samples available in the archive for use. Note that a significant quantity of material is likely to be required due to the high fraction of aluminum that will dissolve. Ideally, there would be a minimum of 40 to 50 g of solids left after water addition.

The objective of testing would be to assess the settling rate at different solids loadings for the sludge fraction and assess particular the fractionation of aluminum and chromium with water addition for the salt cake fraction. In addition, the settled solids loading, the centrifuged solids loading and the settling rate at various solids loadings should be assessed for the salt cake fraction.

Table 4. Breakdown of Al from salt (BBI Al values).

Tank	Sludge Al Inventory (kg)	Saltcake Al Inventory (kg)	Mass Ratio (sludge:saltcake)
U-105	31,677	29,245	1.08
U-107	23,270	25,588	0.91
U-108	17,344	39,020	0.44
U-109	27,907	24,138	1.16
Total Al mass	100,198	117,991	0.85

Reference: https://twins.hanford.gov/twinsdata/home

8.6 Saltcake Only

The tanks in this grouping contain only saltcake with no significant sludge phase identified. Figure 16 presents the saltcake composite that was previously tested by Fiskum et al. (2008). The residual solids were found to contain predominantly aluminum and chromium that appear to mixed in an amorphous phase.

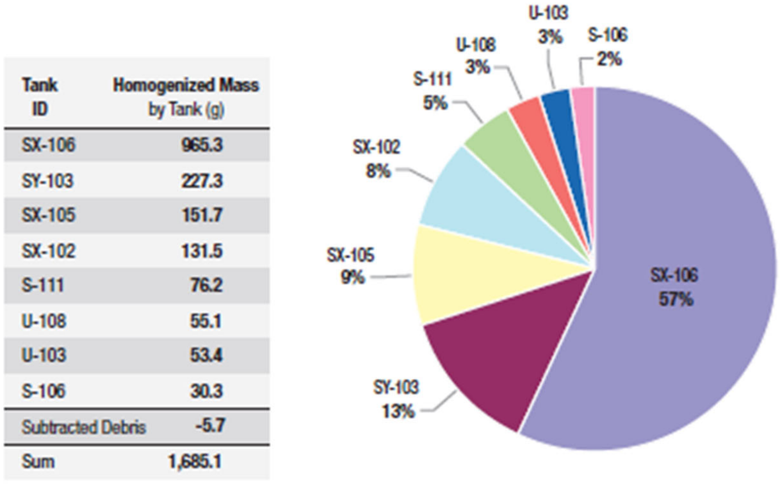
Roughly 40% of the aluminum in the parent saltcake matrix was water soluble, while only around 9% of the chromium was water soluble. The ratio of aluminum to chromium by mass in the parent salt matrix was 3.05. The resultant solids settled to 24.8 wt% with a slurry density of 1.45 g/mL. This material centrifuged to 41.4 wt% with a slurry density of 1.45 g/mL. The supernate density was 1.23 g/mL. The settling rate was measured only at 14.7 wt% undissolved solids.

Table 5 provides a select breakdown of this fraction. Additional testing should assess the settling rate at various solids loadings, and specifically at solids loading closer to those expected during retrieval operations (i.e., at lower than 15 wt%). The fractionation of aluminum and chromium with water addition can also be verified.

Table 5. Composition of water insoluble fraction from S-saltcake sample composite.

Analyte (µg/g)	S-Saltcake
Al	187,000
Cr	92,850
Fe	14,700
Mn	4,680
Ni	1,035
P	2,230
Si	15,500
Sr	54
U	6,575

Source: Fiskum et al. 2008



Tank ID	Homogenized Mass by Tank (g)
SX-106	965.3
SY-103	227.3
SX-105	151.7
SX-102	131.5
S-111	76.2
U-108	55.1
U-103	53.4
S-106	30.3
Subtracted Debris	-5.7
Sum	1,685.1

Figure 16. Nominal mass distribution of S-saltcake tank wastes in the REDOX Saltcake and 242-S Evaporator Bottoms composite.

The samples of S-106 selected for testing in FY25 have an Al:Cr ratio of 3.28 (Field 1998). This ratio is consistent with what was seen in the prior test (Fiskum et al. 2008) and in observations of other saltcake samples. This sample is expected to provide a reasonable measure of the dissolution behavior for the salt-only tanks. However, the support for this assumption is limited; obtaining these data from archive sample analysis will reduce the uncertainty for subsequent processing decisions.

8.7 R1 Non-boiling

To date, no data existing on this waste type relative to aluminum and chromium fractionation with water addition, nor on the physical properties of this waste type. There are three tanks that have predominantly R1 non-boiling sludge (see Table 6). As seen in Table 6, the majority of the aluminum from these tanks is from the sludge. This is the phase that is of most interest to assess the properties of R1 non-boiling waste. Tank U-101 would be an excellent candidate for testing; however, there are no samples available for that tank. S-102 has seen significant retrieval activity since the core samples were taken, and as such, these cores are unlikely to reflect the current state of the tank. That leaves U-102 as the candidate for analysis. There is a significant amount of archive material available from that tank. The characterization of the segments from this tank shows a significant increase in the Al:Cr ratio in the bottom segments. Segments 143:5A, 143:5B, 143:6, 144:6 UH and LH, and 144:6A all have higher Al:Cr ratios, with an average ratio of 13.8 (Hu 1999). These samples should be satisfactory for settling tests but may not be sufficient for a shear strength measurement.

Table 6. Ratio of aluminum sources from BBI for sludge and saltcake for R1 non-boiling wastes.

Tank	Sludge Al Inventory (kg)	Saltcake Al Inventory (kg)	Mass Ratio (sludge:saltcake)
S-102	24,410	4,216	5.79
U-101	23,742	-	-
U-102	50,853	25,530	1.99

Source: https://twins.hanford.gov/twinsdata/home (U-101 has no saltcake phase)

8.8 R2

The final significant source of solids would be from R2 waste. The only tank in the retrieval sequence that contains R2 sludge is SX-110. Unfortunately, there are no samples of SX-110 available. The other tank that contains only R2 solids is SX-115. There is approximately 40 g of material available from this tank.

9.0 Summary

Although close records were kept of original waste disposition at Hanford, the degree of tank-to-tank transfers, waste reprocessing, evaporation, and conditions that impede equilibrium complicate efforts to understand the chemistry, phase composition, and rheology of the waste. A first order simplifying assumption often used in design and analysis is that as saltcake is dissolved, it will physically and chemically resemble the supernatant that formed its basis. However, prior laboratory analyses and field operations have demonstrated that a significant fraction of the material present in saltcake will not dissolve with water addition.

Evaporator concentrates (saltcake) have been observed to have widely varying compositions and solubility behavior that often resist dissolution or behave unexpectedly using deployed waste retrieval technologies. The variability of this mineralogy that will be encountered during retrieval and processing of the 200W tanks is a significant uncertainty regarding the performance of the various unit operations and process control procedures being considered. Tank waste slurries and sludges comprise particles and aggregates from nano to micro scales, with varying densities, morphologies, heterogeneities, compositions, and complicated responses to flow regimes and process conditions. Further, remnant or changing radiation fields and temperature gradients may affect the stability and rheology of the waste. These conditions pose challenges for transport through conduits or pipes to process settling and staging tanks and subsequently to downstream unit operations for solidification (Peterson et al. 2018).

Additionally, recalcitrant boehmite or other insoluble aluminum compounds can introduce unacceptable amounts of insoluble solids to the settling tank that can exceed the tank's operating height, halting processing. Recent advances in situ microscopy, aberration-corrected transmission electron microscopy, theoretical modeling across scales, and experimental methods for probing the physics and chemistry at mineral-fluid and mineral-mineral interfaces are being implemented to build robustly predictive physics-based process models and quantify waste form parameters for evaluating transportation and disposal requirements (Peterson et al. 2018).

Data gaps identified include:

- The chemistry of Al (and Cr) in the waste is distinct from 200E. The use of Al and Cr in REDOX, the relative amounts of waste influenced by the wide range of Al solubility and speciation, and the self-boiling character of the waste makes the chemical behavior different from tanks in 200E.
- Settling behavior (both as-is and under retrieval/settling conditions in SY-103) is not well understood for West Area retrieved solids. Additional data are needed to improve modeling fidelity and process engineering design for WATT.
- The rheology and transport behavior during retrieval (saltcakes and sludges, especially in piping) for West Area residual solids will likely be significantly different from those experienced in 200E retrievals.

Table 7 identified archive samples for analysis that can address the identified data gaps. These recommendations align with the findings in Assmussen et al. (2025), "West Area Tank Treatment Program Solids Accumulation Roadmap."

Table 7. Proposed priority for archive sample analyses.

Tank	Major Solid Phase	Waste Type[1]	Near-Term Ranking for Archive Sample Analysis	Rationale
241-S-106	Salt	Salt	1	Need to provide physical property data, in particular settling data, for solids residual from saltcake dissolution and lower solids loadings
241-SX-102	Salt	(with R1)	2	Provide a comparison to see if the inclusion of R1 with saltcake significantly impacts the fraction of aluminum that dissolves and the resultant physical properties.
241-S-110	Sludge	R1-B	3	Sampled with relevant data available. Select either 241-S-110/S-111 to confirm properties (large volume contributors). Need to assess settling rate for sludge fraction and fractionation of aluminum and chromium in the salt cake fraction.
241-S-111	Sludge	R1-B		
241-U-109	Sludge/Salt	CWR	4	Need to assess the settling rate and aluminum and chromium fractionation for the salt cake phase and verify CWR sludge performance at variable solids loading.
241-U-108	Sludge/Salt	CWR	5	Need to assess the settling rate and aluminum and chromium fractionation for the salt cake phase
241-U-102	Sludge	R1- NB	6	Non-boiling REDOX waste. There are no high-fidelity data regarding waste properties.
241-SX-110	Sludge	R2	7	There are no high-fidelity data regarding waste properties/No archive available; thus, substitute material from 241-SX-115.
241-U-111	Sludge/Salt	1C/R1	8	1C sludge could use properties data collected from 200E tank samples.

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[1] Waste Type labels are from Agnew et al., 1997 (e.g. R1 is early REDOX process waste. CWR is cladding waste from REDOX)

10.0 References

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