SRS Defense Waste Processing Facility – the Nation's Only Operating Vitrification Facility – Completes 20 Years of Radioactive Operations – 17407

Mark Schmitz *, Thomas Foster *, Vijay Jain *
* Savannah River Remediation

ABSTRACT

Savannah River Remediation (SRR) is the current Liquid Waste contractor at the U.S. Department of Energy's (DOE) Savannah River Site (SRS), located near Aiken, South Carolina, and operates the Defense Waste Processing Facility (DWPF), along with the other SRS liquid waste facilities. The DWPF, the nation's only operating vitrification facility, completed 20 years of radioactive operations in 2016. During this period, DWPF has safely treated the high-level liquid waste at this DOE facility since radioactive operations began with the first transfer of sludge waste feed to DWPF on March 12, 1996. A little over a month later, on April 29, 1996, the first radioactive canister was poured. DWPF poured its 4,000th canister of vitrified waste on December 31, 2015. As of September 30, 2016, DWPF has removed approximately 59.9 million curies from the liquid waste system at SRS and placed them in 4,106 canisters.

SRS has operationally closed 8 high-level waste tanks. The DWPF melter has poured nearly 7.14 million kg of molten glass, and the facility has used only two melters in its lifetime. Melter 1 poured 1,339 canisters (1996-2002), while melter 2 to date (September 30, 2016) has poured 2,767 canisters (2003-present). Melter 2 continues to safely and efficiently operate.

In order to achieve these accomplishments, the facility has chronicled a history of continued operational improvements such as the installation of bubblers in the melter to increase production, incorporation of glass compositions to achieve higher waste loadings, and improvements to melter design to extend melter life.

As SRR moves forward to the next 20 years, continued improvements as well as maintaining the aging infrastructure through a proactive system health program are key priorities. This paper chronicles 20 years of challenges, improvements and accomplishments, and discusses future operations and infrastructure upgrades including implementation of a key flowsheet change to significantly reduce hydrogen generation in the Chemical Process Cell.

INTRODUCTION

The SRS liquid waste system (LWS) is an integrated series of facilities (as shown in Figure 1) that safely manage the existing waste inventory and disposition of waste stored in the tanks into final glass or grout form. The large underground storage tanks and associated equipment, known as the “Tank Farms”, include a complex interconnected transfer system with underground transfer pipelines and ancillary equipment to direct the flow of waste. The waste in the tanks is present in three forms: supernate, sludge, and saltcake. Supernate is clear liquid containing most of the cesium (Cs) and soluble salts; salt cake, which consist of crystalized salts of nitrates, nitrites, sulfate, etc.; and the sludge consists of undissolved solids mostly oxides/hydroxides of iron and aluminum including actinides (majority of the radioactivity is from strontium-90) and entrapped supernate. The waste from these tanks is retrieved and treated as sludge or salt. The high-level (radioactive) fraction of the waste is vitrified into a glass waste form, while the low-level waste is immobilized in cementitious grout waste called saltstone. Once the waste is retrieved and processed, the tanks are closed via chemical cleaning, heel removal, stabilizing remaining residuals with tailored grout formulations, and severing/sealing external penetrations. The comprehensive liquid waste disposition system, currently managed by SRR, consists of:

- Safe storage and retrieval of the waste as it is prepared for permanent disposition;
- Definition of the waste processing techniques utilized to separate the high-level waste (HLW) fraction/low-level waste (LLW) fraction;
- Disposition of LLW in saltstone;
- Disposition of the HLW in glass; and
- Closure state of the facilities, including tanks.

The only operating radioactive waste vitrification plant in the country (Figure 2), DWPF converts the high-level liquid nuclear waste into a solid glass form suitable for long-term storage and disposal. Facility construction began in late 1983 and waste qualification testing was completed in late 1995, filling 70 canisters with a nonradioactive glass form that met all environmental and operational requirements. Nonradioactive chemicals simulated the properties and constituents of the waste. DWPF began radioactive operations in March 1996 and poured its first radioactive canister on April 29, 1996. SRR is projected to produce approximately 8,170 canisters of the vitrified high-level waste. [1]

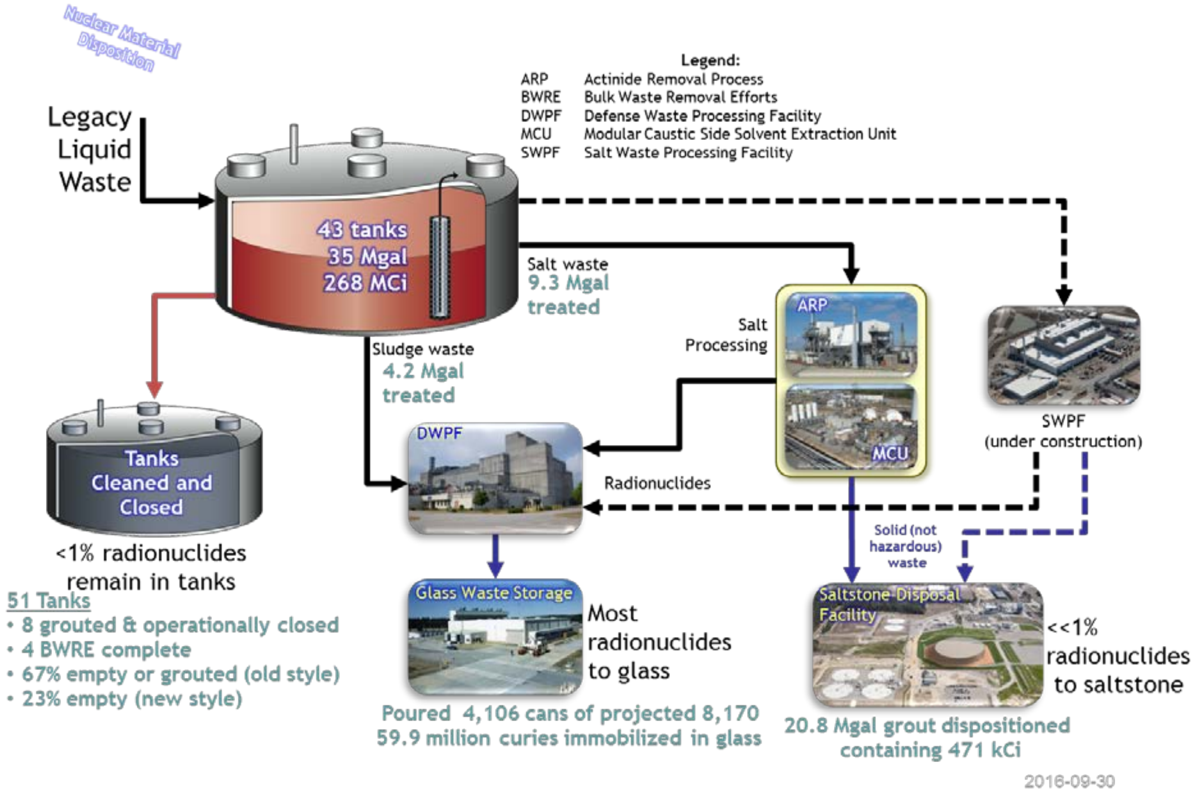

Fig.1 SRR Liquid Waste System

Fig. 2. Defense Waste Processing Facility.

At the heart of the DWPF is the melter (Figure 3), which weighs 68.5 tons (including vessel, frame and components). The melter was originally designed to last for a minimum two years. Due to the robust design of the DWPF facility and the melters, the type of waste processed, and the successful implementation of innovative design improvements, the life of the melter has been extended. To date, the production rate for the two melters has been outstanding. Melter 1 poured 1,339 canisters (1996-2002), while melter 2 to date (September 30, 2016) has poured 2,767 canisters (2003-present).

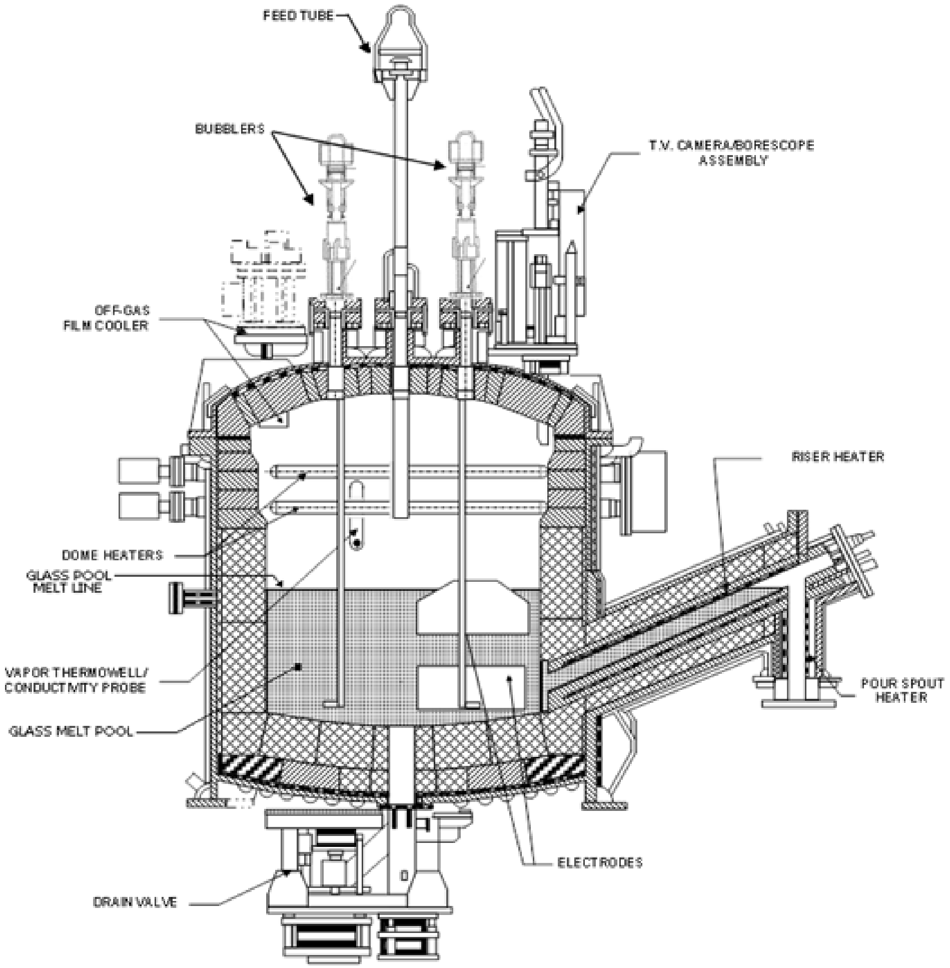

Fig. 3. Defense Waste Processing Facility Melter.

Two additional melters have been purchased and assembled and are now stored onsite. When the decision is made to replace melter 2, it is estimated that it will take four months to remove the old melter, install the new one, test it, and return to normal operations. All operations are conducted remotely to protect workers from radiation.

Melter Design Improvements

Innovations included the redesign and installation of technologies that improved the melter pour rate and provided necessary improvement for ongoing cleaning and maintenance, which allows the melter to continue operating with minimum outages. These include:

- Development of a removable insert to restore the “knife-edge,” which allows disengagement of the glass pour stream from the pour spout;
- Installation of the heated bellows liner to provide additional heat to the pour spout;
- Installation of a pour stream viewing camera, which allows monitoring of the glass pour stream from the control room; and
- Deployment of a remote system to repair leaks in the melter cooling water system.

Melter 2 glass production capabilities have been enhanced first by installation of a glass pump and later by installation of bubblers, which inject argon gas bubbles into the melt pool. This enhancement improved the heat transfer in the melt pool and keeps the molten glass at a more uniform temperature, which increases the melt rate and allows for higher production rates. Bubbler technology increased the production of vitrified waste by 50 percent.

Glass Pump Technology

To improve the melt rate of high-level waste slurry feed being vitrified by the DWPF melter, a glass pump was installed on February 10, 2004. The glass pump increased the melt rate by generating a forced convection within the molten glass pool, thereby increasing the heat transfer from the molten glass to the unmolten feed cold cap that is on top of the glass pool. After operating for over four months, the pump was removed on June 22, 2004, due to corrosion. This led to the pump being redesigned to improve its mechanical integrity (increased wall thickness and strength) while maintaining its hydraulic diameter as large as possible. The improved DWPF glass pump was installed on September 15, 2004. The pump was effective in increasing heat transfer to the cold cap, thereby increasing melt rate by at least 5 -10% and in stabilizing melter operation by minimizing high upper glass temperature interlocks and increasing the lower glass pool temperature.

Bubbler Technology

In order to achieve higher waste throughput, the DWPF needed to increase its production rate of radioactive waste glass filled canisters. Four bubblers were designed and installed in existing nozzles on the top-head of the DWPF melter (replacing the glass pump) in September 2010, to agitate the molten glass pool. Operations of the bubblers accomplished the goal of increasing the glass production capability of the DWPF melter. Bubblers continue to be used since initial installation. As a result of the higher glass production rates with bubblers, the DWPF has set monthly, fiscal year, and 12 month rolling canister production records. These accomplishments can be directly attributed to the bubblers ability to increase mixing/convection within the glass melt pool, thereby improving the heat transfer from melt pool to the cold cap. Furthermore, this has helped SRR take a significant step forward toward closing the HLW tanks.

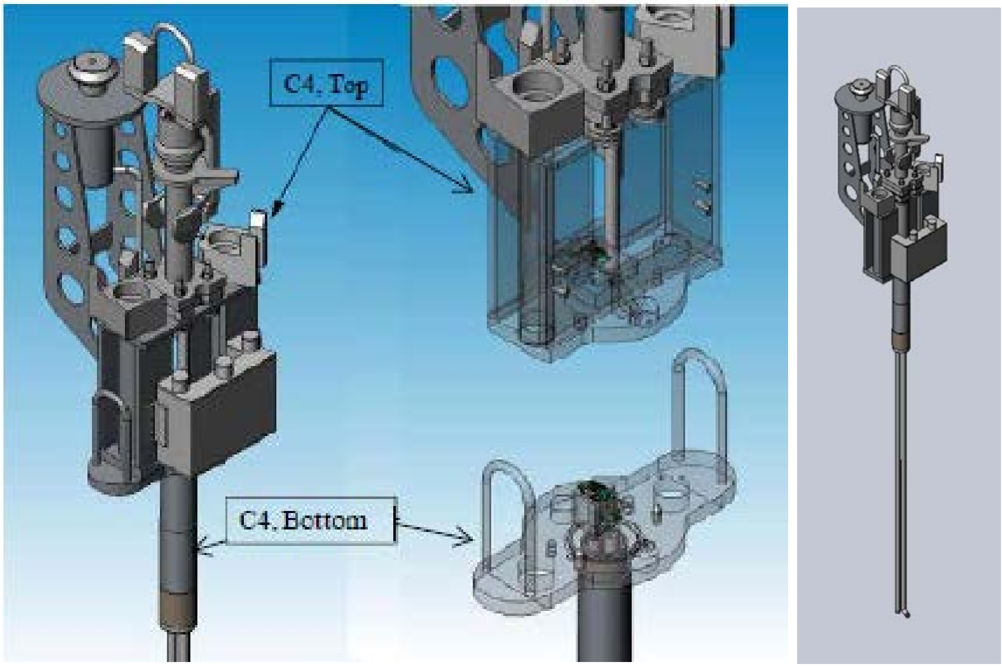

Fig 4. DWPF melter bubbler design.

Since the bubblers have to be replaced after six months of melter operations due to corrosion, they were redesigned to allow reuse of the more costly and more difficult to dispose of bubbler upper portion that is not exposed to the inside of the melter. A new less expensive thermocouple design has also been successfully implemented.

With the increase in the sulfate levels in the glass in the last few sludge batches processed at DWPF, there were some concerns as to whether or not the bubblers could still last in the melter for the cited 6 months. After failure of one bubbler pipe at the melt line, protective sleeves were added to the bubbler pipes at the melt line. This has helped to ensure at least a 6 month usage life in the melter. DWPF is continuing to explore opportunities to extend the design life of the bubblers beyond six-months.

Double Stack Storage of Canisters

DWPF pours molten HLW glass from the melter into the stainless steel canisters for long-term storage and disposal. The canisters are placed into interim storage in Glass Waste Storage Buildings (GWSB) No. 1 and 2. Building No. 1 has four underground reinforced concrete vaults where 2,262 canisters can be stored in an array of positions. Each position consists of an elevated steel cross bar – “bearing bars” support base – for the canister and a 4-foot thick concrete plug that is flush with the operating floor of the building as shown on the left side of Fig. 5.

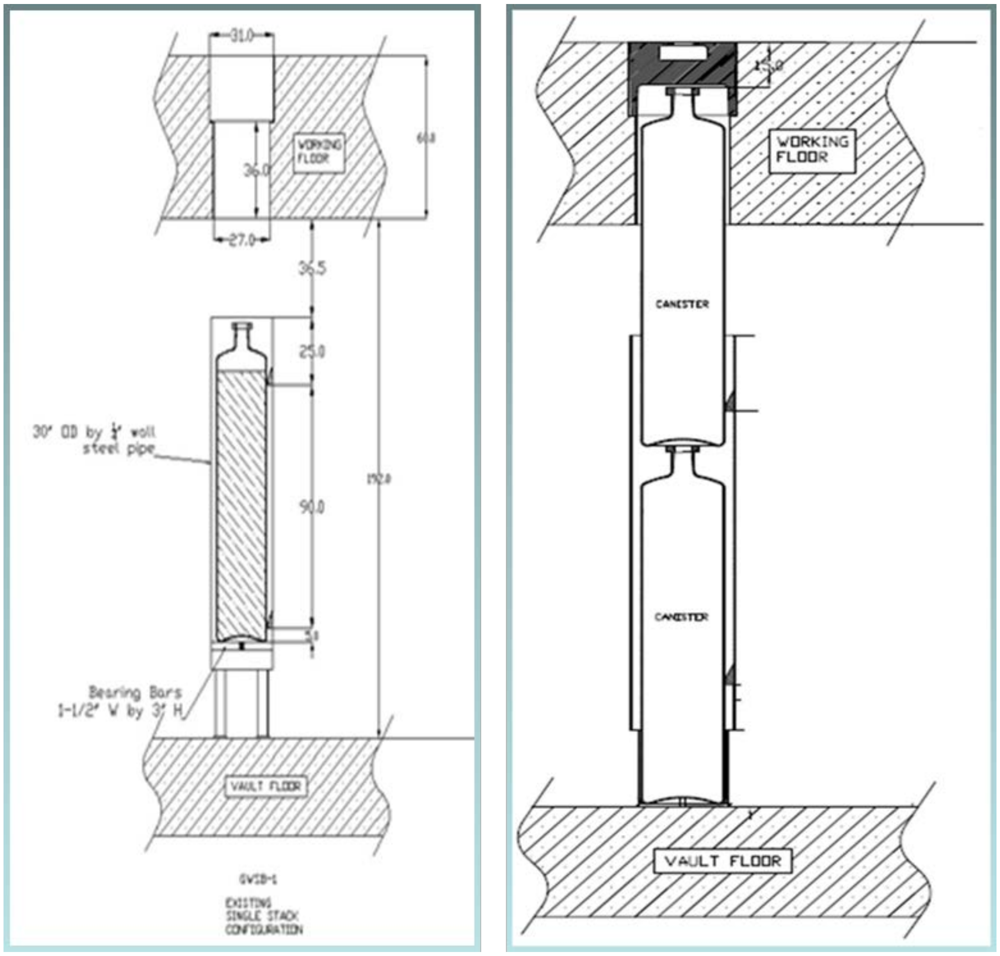

Fig. 5. Original Design (Left) and Modified Design (Right) of the Glass Waste Storage Building #1.

In order to increase its storage capacity, Building No. 1 is being reconfigured to place two canisters into each position as shown on the right side of Fig. 5. The modifications include removing the current canister steel support (shown as bearing bars in Fig. 5) and replacing the concrete shield plug with a tapered galvanized cast iron floor plug that will provide radiation shielding. These modifications will effectively double the storage capacity of GWSB No. 1 to 4,524 canisters and create adequate canister storage through fiscal year 2026. In FY16 SRR completed modifications to 150 canister positions, including crossbar support removal, installation of new support plates, and shield plugs. Benefiting from the cutting tool efficiency, SRR was able to remove an additional 110 crossbar supports. In August 2016, SRR successfully demonstrated canister double-stacking capabilities when two radioactive canisters were stacked in one storage position in GWSB 1. SRR has now begun double- stacking of the canisters.

VITRIFICATION PROCESS

Fig. 6 shows DWPF flowsheet. Nominally, 22,500 L of sludge is received on a batch basis in the Sludge Receipt and Adjustment Tank (SRAT) from a 3.7 million L feed tank. The sludge is chemically adjusted in the SRAT via addition of concentrated nitric and formic acids. The purpose of the chemical adjustment is to acidify the incoming sludge to adjust the rheological properties to improve processing, remove mercury from the sludge feed, and to prepare the sludge feed for melter operation by controlling the reduction/oxidation state of the glass. The SRAT also receives and processes an actinide-rich stream containing primarily monosodium titanate solids as well as a cesium-rich dilute nitric stream from salt processing. Following chemical adjustment and concentration in the SRAT, the sludge material is transferred to the Slurry Mix Evaporator (SME) where the material is blended with frit slurry. The SME represents a hold point in the process to ensure the batch will produce acceptable glass (based on statistical process control rather than statistical quality control). Upon confirmation that the blended SME material is acceptable, the material is transferred to the Melter Feed Tank (MFT), which represents a transition in the process from a batch to a continuous process, as the slurry in the MFT is continuously fed to the melter. During normal operation, the melter constantly receives a small stream of slurry from the MFT (nominally 3.8 L/min). The slurry is deposited on top of the molten glass pool which is heated via two sets of electrodes that pass current through the glass pool (Joule heating). The slurry then melts into the molten glass pool as the molten glass is vacuum poured into stainless steel canisters. Since commencing operations in March 1996, the DWPF has processed approximately 21 million L of radioactive sludge slurry over the course of eight discrete sludge batches. In addition, the DWPF has successfully incorporated receipt an actinide-rich stream containing primarily monosodium titanate solids and a cesium-rich dilute nitric stream from salt waste processing into waste glass production since 2007.

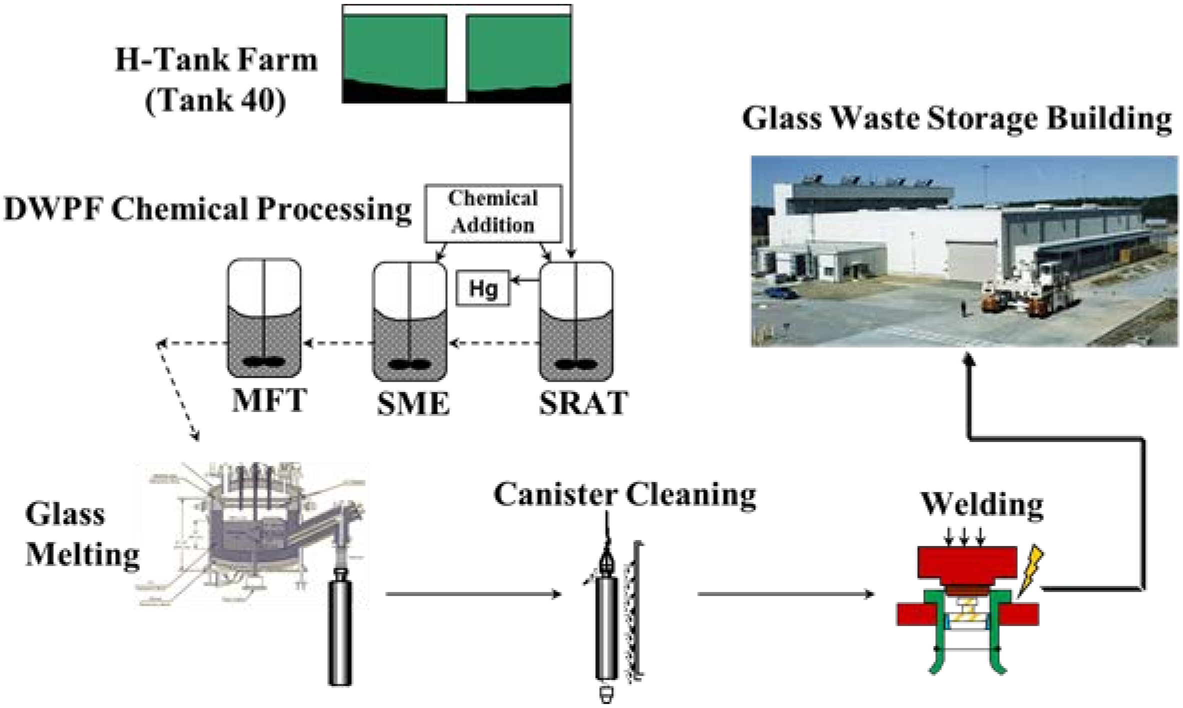

Fig. 6. Defense Waste Processing Facility Process Flowsheet.

Vitrification Process Improvements

Initial operations at the DWPF were conservative to ensure the facility could be operated within its safety basis while producing a qualified product. As the operations progressed and performance data was collected, several initiatives were undertaken to optimize and enhance the glass production rate. Changes to melter feed preparation (encompassing chemical adjustment and blending with frit) were achieved through process optimization, requiring minimal cost and risk to the facility. These improvements included the reduction of analytical cycle time as well as reducing the impact of the analytical cycle time on the overall process. For example, new sampler stations were installed in the analytical cells, which reduced downtime related to equipment failures and decreased sample turn-around time. In addition, certain analyses are now performed in parallel with processing (i.e. “sample-and-send”), significantly improving cycle time while adding no new risk to the facility. Throughput was increased by performing a cost/benefit analysis of the sludge transfer from the Tank Farm to the DWPF evolution resulting in more mass of insoluble solids treated per batch.

Combined efforts to reduce the overall cycle time required to produce melter feed and increase throughput through the DWPF improved facility production by approximately 25%. Since the installation of melter bubblers and associated optimization of the melter feed preparation in 2010, a record number of canisters have been produced. Prior to 2010, DWPF had produced 30 or more canisters in a month on 3 occasions (all in 1998). Since implementation of facility improvements, the DWPF has achieved monthly canister production numbers in excess of 30 canisters in 8 separate months, including a record of 40 canisters produced in the month of August 2013. In addition, the facility demonstrated the capability (based upon an instantaneous twelve month rolling total) to produce up to 337 canisters in a given year (June 2011 – June 2012), which is the highest rolling twelve month total observed since commencement of operation in March 1996. This increase in production has been achieved in conjunction with an increase in waste loading (defined by the mass of calcined waste per mass of glass produced), resulting in more overall sludge throughput in the DWPF. Subsequently, SRR has closed 6 HLW tanks.

Glycolic-Nitric Acid Flowsheet

Currently, DWPF uses a nitric-formic acid flowsheet to chemically adjust the sludge slurry prior to vitrification in the melter. Prior to facility start-up in 1996 the nitric-formic acid process required extensive modifications to the process ventilation systems due to catalytic hydrogen produced from formic acid in the presence of noble metals (rhodium, ruthenium, palladium, and silver). In addition to the increased purge required, safety significant gas chromatographs (GC) were required to monitor hydrogen and shut down the process if high levels of hydrogen are measured to ensure that flammability controls are maintained. The Alternate Reductant Project was initiated by SRR to explore options for the replacement of the nitric-formic flowsheet used for the Chemical Process Cell (CPC) at DWPF. The primary goal of the Alternate Reductant Project is to reduce operational hazards in regards to catalytic hydrogen production in the CPC. The Alternate Reductant Project will replace formic acid used in the CPC with glycolic acid. Acid is added for initial neutralization of the sludge feed, reduction of mercury, and to ensure glass REDOX is within the existing range for melter operation. The replacement of formic acid with glycolic acid will significantly reduce catalytic hydrogen generation in the CPC. The role of glycolic acid in the CPC will be sufficiently similar to that of formic acid that physical modifications will be minimal. While the primary benefit of glycolic acid is the reduction in catalytic hydrogen generation, additional benefits from glycolic acid and reduced catalytic hydrogen include: potential reduction of the process vessel purge, potential downgrading of the functional classification or elimination of the GCs, more favorable rheology potentially allowing more concentrated feed to the melter, less foaming in process vessels, less surge of non-condensable gases from the melter cold cap, and a more favorable flammability control envelope for both the melter and the CPC. Major research and development activities have been completed. The qualification of the flowsheet using real waste demonstrated that glycolic acid performs its function effectively and produces very little hydrogen during processing. Figure 7 compares the hydrogen generation rate in the current nitric-formic flowsheet and glycolic-nitric flowsheet using simulants. [3]

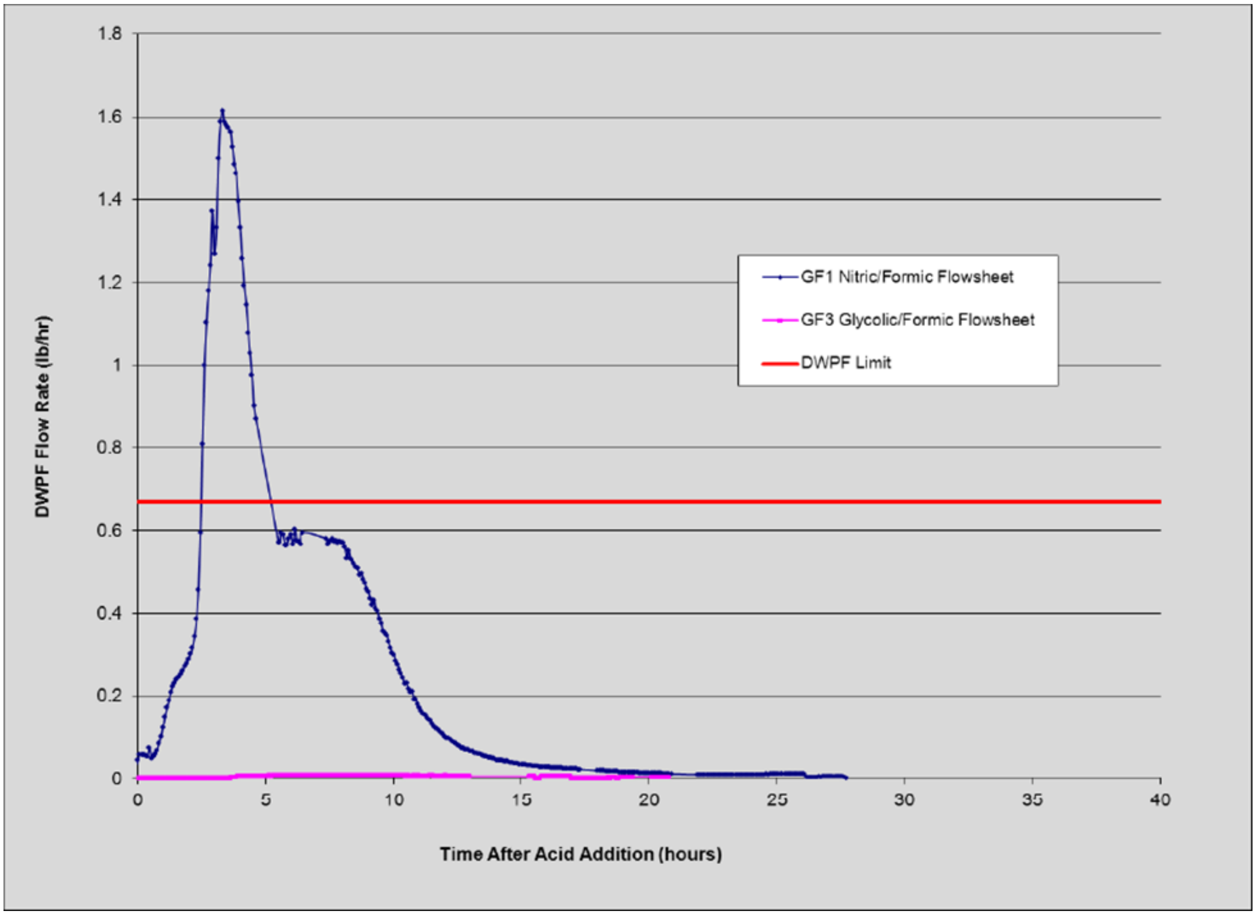

Fig. 7. Hydrogen Generation Comparison between Formic Flowsheet and 80/20 Glycolic/Formic Blend.

The project team is currently executing an implementation schedule which addresses safety basis development, revision to operations procedures and training, facility modifications, chemical procurement, and updated process monitoring. Introduction of glycolic acid into DWPF is currently scheduled to take place in early 2017, beginning with a blended flowsheet of glycolic and formic acid, and ultimately transitioning to glycolic-only processing.

Several other initiatives are also on-going which address a reduction in the amount of recycle water generated by the facility and sent back the Tank Farm for processing. A reduction in the amount of water added to the facility via various unit operations has the potential to significantly reduce cycle time of the DWPF while reducing the burden on the Tank Farm evaporators. Lastly, the facility is working a number of initiatives in anticipation of accommodating product streams from increased salt waste throughput. The desire is to create flexibility within the facility to be able to integrate with ongoing initiatives to increase salt waste processing.

WASTEFORM PROPERTIES AND MODELS

Borosilicate based glass wasteforms have been widely used in the United States and in Europe to immobilize radioactive HLW for ultimate geologic disposal. Waste glass formulations are designed to simultaneously balance multiple product/process constraints as shown in Table 1. Waste forms are also designed to maximize the concentration of waste in the vitrified waste form (waste loadings) so that waste glass volumes and the associated storage and disposal costs are reduced.

Table 1. Waste Glass Product and Process Constraints

Product Constraints	Process Constraints
Chemical durability	Melt viscosity
Glass homogeneity	Melt resistivity
Thermal stability	Liquidus
Mechanical stability	Solubility limits
Regulatory compliance	Melt temperature/corrosivity
	Radionuclide volatility
	Redox

SRR uses the Product Composition Control System (PCCS) developed on-site as a tool to evaluate SME batch acceptability of the waste for processing. The PCCS models factor in the analytical and sampling errors of the DWPF facility when predicting the properties of the glass. The glass properties that are assessed with PCCS are shown in Table 1. In addition, an experimental glass variability study is performed to ensure that the models apply over the anticipated glass composition region. Solubility limits for sulfur is also evaluated and updated if necessary during the qualification process. The DWPF original baseline flowsheet assumed a 28 weight % sludge waste loading. The baseline also assumed one frit for sludge-only processing.

Waste Form Improvements

As DWPF operations matured, it provided performance feedback which served as the basis for the development of alternative strategies to support continuous improvement activities associated with both flowsheet development activities and qualification requirements.

Glass formulation strategies have shifted from a “one frit fits all” concept (i.e., a single multi-component frit composition that would work for every batch) to tailoring specific frits for each sludge batch [typical volume of a sludge batch is 3.78 million L (1 million gal)] in order to optimize sludge preparation, increase waste loading and improve throughput – all of which have a positive impact on reducing the overall mission life of the Tank Farm and DWPF facilities. These efforts have served as technical bases for DWPF's continuous improvement efforts since initial DWPF operations began in 1996.

Development and implementation of new glass property models (e.g., a liquidus model) and an alternative approach for defining acceptance limits for durability coupled with strategic frit development efforts have resulted in significant increases in waste loading relative to the baseline. Since implementation of these alternative approaches, targeted waste loadings have increased to 38%.

Expanded Glass Processing Region to Support Salt Waste Processing Facility

With the planned integration of Salt Waste Processing Facility (SWPF) into the DWPF, higher volumes of strip effluent and actinide streams at higher concentrations will have to be processed through the DWPF. In addition to the increased volume of the new streams, the stream compositions present the challenge of higher sodium and titanium concentrations. The original 1996 TiO_2 limit in the glass was a solubility based limit. In 2003 based on testing of additional glasses, the TiO_2 glass solubility up to 2 weight % was established in the PCCS model. [4] A statistically designed glass composition matrix was developed to expand the current glass processing region that was based on the high level waste feeds documented in Reference 1 with integration of the SWPF streams that would incorporate TiO_2 compositions up to 5.8 weight %. The study provided 50 glass compositions that covered both the extremes of the expected glass compositions as well as compositions designed to make the PCCS model data bases (viscosity, durability, and liquidus) more robust. The PCCS models are being updated to provide expanded glass processing region to support integrated SWPF operations.

INFRASTRUCTURE

When the DWPF was commissioned for cold-chemical startup runs in 1990 it was the newest processing facility at SRS, a site where most processing and waste storage facilities dated from the 1950s. Combining state-of-the-art design and materials of construction with a strong technical baseline, DWPF represented the flagship facility among several process areas used to implement an integrated flowsheet for waste retrieval, treatment, and disposal. However, after processing several million liters of HLW sludges and pouring thousands of kilograms of vitrified-glass in the stainless steel canisters, DWPF is past twenty years of radioactive operations and faces challenges now that were unusual or absent from its early processing history. Facility conditions due to age and radiological contamination have increased the level of effort required for maintenance in parts of the facility, and equipment obsolescence has begun to complicate repair efforts. While these issues are expected at this point in a facility life-cycle, it underscores the need for pro-active management to ensure that DWPF will continue to operate at a high level of reliability for years to come.

Aging infrastructure management is included as a part of general system health and performance monitoring under a related program. The net effect of these programs is to implement a graded approach which considers the following to determine whether residual vulnerability exists and define additional actions necessary to ensure that components will perform their function in a manner consistent with the period of expected operations.

- Asset value (safety function, importance to production support, etc.)
- Design details (active vs. passive component, materials of construction, redundancy)
- Service environment
- Degradation mechanisms
- Applicability of existing management programs (preventive maintenance, structural integrity, etc.)

DWPF recently completed a significant overhaul of one of its safety systems [2]. Chemical processing of HLW sludges within DWPF can generate substantial quantities of hydrogen, which represent a flammable hazard if allowed to accumulate in vessel vapor spaces. The DWPF uses a forced purge system (supplied by either compressed air or nitrogen) that sweeps the vapor spaces of affected tanks and prevents flammable gas accumulations. In the original design for this system, the purge gas flowed through redundant measurement instruments located within a personnel service corridor before reaching the remotely-located process vessel. One of the instruments was a locally-indicating rotameter, while the other was a thermal element with monitoring and alarm functions that were output to the distributed control system (DCS). The simple mechanical design of the rotameter required relatively little service beyond calibration verification, but the more complex operation of the thermal element necessitated off-site vendor support for periodic maintenance and calibration. As years passed, the manufacturer continued to update the design of their flow instruments and began to indicate that they would likely cease offering service on the older units. The engineering team decided to replace the older style equipment with the new design to achieve consistency across all the vessels and realize the benefits of the new configuration as well. The forward-looking aspect of the viability assessment proved to be important. The equipment was part of a Vital Safety System, and it is assumed to be available at all times. The equipment is qualified to withstand earthquakes and Technical Safety Requirements (TSRs) required the facility to repair the system within hours to a few days (depending on processing conditions) if the system became inoperable. In order to accomplish this task, the design implementation was broken into intrusive and non-intrusive segments. The design changes were developed and non-intrusive work was performed while the original equipment continued to operate. The final intrusive modifications and startup testing were completed over the span of a few weeks in the spring of 2015. The successful execution of this modification required the integrated effort of almost every line organization within the DWPF. From start-to-finish the effort required more than two years of preparation and planning, and was completed with a minimum impact to processing operations.

In addition to address issues related to an aging facility, a review team was commissioned to evaluate current practices and to identify improvement opportunities to ensure sustainable production at the DWPF. [5] Recommendations were identified in key areas such as:

- Asset preservation;
- Facility housekeeping; and
- Process improvements.

Since issuance of the plan, significant progress has been made in each of these areas to improve the reliability and predictability of the DWPF.

SUMMARY

SRR operates the DWPF, along with the other SRS liquid waste facilities. DWPF, the nation’s only operating vitrification facility, completed 20 years of radioactive operations in 2016.This paper chronicled 20 years of challenges, improvements and accomplishments. The facility has a history of introducing new technologies and innovations that have continued to improve and optimize the process. Some of the accomplishments include improvements to melter design to extent melter life, installation of bubblers in the melter, double-stacking of canisters, optimization of the process flowsheet, development of sludge-specific strategy for frit design and robust models that have increased waste loadings. As SRR moves forward to the next 20 years, continued process improvements, incorporations of new technologies and maintaining the aging infrastructure through proactive system health program are key priorities. One of the key infrastructure upgrades includes implementation of a glycolic-nitric acid flowsheet that significantly reduces hydrogen generation in the CPC.

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