The Defense Waste Processing Facility: Two Years of Radioactive Operation

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ABSTRACT
The Defense Waste Processing Facility (DWPF) at the Savannah River Site in Aiken, SC is currently immobilizing high level radioactive sludge waste in borosilicate glass. The DWPF began vitrification of radioactive waste in May, 1996. Prior to that time, an extensive startup test program was completed with simulated waste. The DWPF is a first of its kind facility. The experience gained and data collected during the startup program and early years of operation can provide valuable information to other similar facilities. This experience involves many areas such as process enhancements, analytical improvements, glass pouring issues, and documentation/data collection and tracking. A summary of this experience and the results of the first two years of operation will be presented.

INTRODUCTION
Approximately 130 million liters of high-level radioactive waste, currently stored in underground carbon steel tanks at the Savannah River Site (SRS), is being immobilized in stable borosilicate glass in the Defense Waste Processing Facility (DWPF). The glass is poured into stainless steel canisters for eventual disposal in a geologic repository. To be acceptable for disposal the DWPF product (i.e. the canistered waste form) must comply with the Department of Energy Office of Environmental Management's Waste Acceptance Product Specifications (WAPS).

DWPF has been vitrifying radioactive waste for approximately two years. DWPF received the first batch of radioactive waste in March 1996 and began vitrification of radioactive waste in May 1996. Since the start of radioactive operations DWPF has operated on a sludge only flowsheet. Prior to the start of Radioactive Operations DWPF went through an extensive Startup Test Program. This structured program allowed the facility to demonstrate its ability to comply with the WAPS, refine operating procedures, and provide training and experience to personnel. However, even with the Startup Test Program, operational and equipment issues have been encountered during Radioactive Operations. The experiences and lessons learned from a first of its kind vitrification facility like DWPF or the facility at West Valley...
can provide valuable insight to the designers and operating staff for future radioactive vitrification/immobilization facilities.

**DWPF PROCESS/PRODUCT OVERVIEW**

The radioactive waste in the SRS Tank Farms has been separated into a water soluble salt solution and saltcake, and an insoluble sludge of metal hydroxides and oxides. The salt solution and saltcake are decontaminated for disposal as low-level radioactive waste by removing the radionuclides by precipitation and sorption. The current baseline process is to add sodium tetraphenyl borate to precipitate soluble salts of primarily potassium and cesium and sodium titanate to adsorb residual strontium and plutonium. The resulting slurry is filtered and the decontaminated filtrate is blended with cement, slag and flyash for disposal at SRS as a low-level radioactive waste. The slurry of the concentrated solids is transferred to DWPF for immobilization. The sludge portion of the waste is washed to remove soluble salts. Thus, the radioactive waste from the SRS Tank Farms is transferred to the DWPF in two forms: precipitate slurry and sludge slurry. The waste is then processed and blended in the DWPF before it is vitrified, poured into canisters, sealed, and placed in interim storage.

The DWPF is currently operating on a sludge only process - no precipitate is being fed to the facility. The sludge is transferred directly to the Sludge Receipt and Adjustment Tank (SRAT) for processing and blending with the precipitate (when that part of the process becomes operable). The current baseline process includes processing of the precipitate in the DWPF Salt Process Cell to remove most of the organic material. When the alkaline sludge is transferred to the SRAT it is neutralized with nitric acid and formic acid (which is added to take the place of the precipitate material). The excess formic acid reduces the mercuric oxide in the sludge to elemental mercury. The elemental mercury is then steam stripped from the SRAT into a holding tank from which it is later pumped and decontaminated. After processing in the SRAT, the slurry is transferred to the Slurry Mix Evaporator (SME) where a borosilicate glass frit is added and the slurry is concentrated to produce melter feed.

The amount of SRAT material and frit to be blended in the SME is determined by the desired glass composition. The region of desired composition is determined by glass property models and statistical algorithms. Any point within the acceptable region can be selected as the target for a particular batch.

The SME is the hold point in the process where feed acceptability is determined as part of the Glass Product Control Program. The Glass Product Control Program ensures that the DWPF produces an acceptable glass product by controlling the composition of the melter feed material. The analyses of samples from the SME are used by DWPF engineers to determine the acceptability of the melter feed. The acceptability of the melter feed is determined using glass property models and statistical algorithms which take into account analytical uncertainty to ensure the glass product will be acceptable and that processing constraints (such as viscosity...
and liquidus) are met. In order for the glass to be acceptable it must be more
durable than the Environmental Assessment glass as measured by the Product
Consistency Test (PCT).

Once the melter feed material in the SME is determined to be acceptable, it is
transferred to the Melter Feed Tank (MFT) and then fed to the joule heated melter.
The DWPF melter has two pairs of electrodes. The feed slurry is introduced from
the top of the melter and forms a crust, or cold cap, on the surface of the melt pool
as the water is evaporated and removed via the off-gas system. The cold cap melts
from the bottom and forms the borosilicate glass matrix. The nominal glass melt
pool temperature is 1150°C. The mixing behavior of the melter was evaluated
during Waste Qualification Runs. The glass is removed from the melter near the
bottom through a riser and pour spout. A vacuum is drawn on the pour spout to
pour the glass. A glass pour stream sample is taken occasionally during filling of a
canister to confirm that the glass durability (as determined by the Product
Consistency Test) is acceptable. During the first year of radioactive operations
several glass pour stream samples were taken and analyzed.

After a canister is filled, a temporary seal is installed to prevent free liquid from
entering the canister during the decontamination process. Decontamination of the
canister surface consists of blasting an air-injected frit slurry against the canister.
The frit slurry from the decontamination process is used in the next SME batch as
part of the required frit addition. The canister is then welded closed and transferred
to an interim storage building. The DWPF canistered waste form contains
approximately 1800 kg of glass. It is 300 cm in length and 61 cm in diameter.

PRODUCTION STATUS

Prior Operations

Prior to the start of Radioactive Operations DWPF underwent an extensive Startup
Test Program. In 1992 DWPF completed integrated water runs testing. In 1993
DWPF began Cold Chemical Runs testing, initiated construction for
hydrogen/ammonia upgrades (ammonium nitrate was found in the vent system of
the DWPF pilot facility). Melter heatup, the initiation of melter feeding, and the
first glass pour were completed in 1994. The Waste Qualification Runs portion of
the DWPF Startup Test Program was completed in 1995. During Waste
Qualification Runs varying feed compositions were used to demonstrate that the
DWPF could control the glass product over a range of materials using the DWPF
Glass Product Control Program. The simulated waste was transferred into the
DWPF and processed using the same methods as for the radioactive waste. The
glass and canistered waste forms produced during Waste Qualification Runs were
extensively characterized. The results of this characterization demonstrate the
DWPF's ability to comply with the WAPS. The Westinghouse Savannah River
Company Operational Readiness Review (ORR) was completed and the DOE ORR
Radioactive Operations

DWPF received the first batch of radioactive waste in March 1996 and began vitrification of radioactive waste in May 1996. During the remainder of the 1996 fiscal year (FY) DWPF produced 69 canisters of borosilicate waste glass. In FY 1997 DWPF produced 169 canisters of borosilicate waste glass and 29 feed preparation cycles. Two of the feed batches required remediation in the SME to correct an unacceptable predicted glass property.

Through March 1998 DWPF has produced 130 canisters in FY 1998. The DWPF production goal for FY 1998 is 200 canisters. Since DWPF began Radioactive Operations almost 300,000 gallons of sludge has been processed to produce over 1.5 million pounds of glass.

Throughout this time period DWPF has continued to operate using a sludge only process with the waste from the first sludge batch (batch 1A). Sludge batch 1A was washed and prepared for transfer to DWPF at the end of 1995. Since there is no aqueous phase from the precipitate waste stream, slight modifications had to be made to the DWPF flowsheet. A frit composition higher in alkali was developed and formic acid was added to the sludge in the SRAT to drive the reduction of certain metals to the correct oxidation state.

The feed composition has remained extremely uniform over time. DWPF will continue to operate off of this first sludge batch until the summer of 1998 when the next batch of sludge will be ready to transfer to the DWPF. The composition of the second sludge batch is relatively similar to the first sludge batch although it has a little more aluminum, a little less iron, a little more mercury, and 3 times the quantity of noble metals (although significantly less than design basis).

EQUIPMENT/PROCESS ISSUES

As with the startup of any new facility, equipment and process issues provide unique challenges. The following sections include discussions of some of the results from the first two years of radioactive operation.

Melter Pouring

To initiate glass pouring a vacuum is pulled relative to the melter vapor space on the canister and pour spout. The glass travels up the riser and overflows into the pour spout. The glass travels vertically down the side wall approximately where the wall of the pour spout is cut back to form a knife edge to allow the glass to disengage and fall into the canister. The glass falls through an unheated bellows and into the canister. At the end of simulant testing the glass pour stream began to contact the unheated bellows or lower section of the pour spout below the knife edge. This
caused the glass to build up and potentially block the flow. Modifications were made to the pour spout to open the lower bore and create a second knife edge. This improved pouring performance but after the start of Radioactive Operations pouring behavior degraded. In an effort to mitigate the problem a number of factors were investigated including: melter and pour spout pressure control systems, using a tele-robotic manipulator (TRM) to physically remove glass buildup, and varying glass pour rate. The TRM has a reach of 330 cm and when fully extended is capable of lifting 45 kg. This is a prototype design and while it has been an extremely useful tool its robustness has been below expectations. All failures have been electrical in nature.

Some improvement was accomplished by optimizing several variables, however, the pouring behavior was still not adequate. It was determined that a physical modification to the pour spout would be needed. A remotely installed, replaceable “insert” (Inconel 690) was installed in the pour spout to lower the glass disengagement point and provide a new disengagement point. The first insert was installed in May 1997. Since that time the insert has been successfully replaced several times. The first insert was characterized after replacement. It was found that some erosion of the knife edge did occur. Production rate dramatically increased after installation of the insert.

Material Performance

DWPF process equipment can be subjected to harsh environments. Chemical corrosion due to halides, sulfates, mercury, elevated temperatures, etc. and erosion due to glass frit particles can be a concern. Performance of the DWPF process equipment has been evaluated through a materials evaluation program prior to radioactive operations and some experience has been gained during the first two years of radioactive operation.

Removable Process Cooling/Heating Coils - Four of the main process tanks (SRAT, SME, MFT, and SMECT) have removable coil assemblies of similar design. The SRAT and SME have cooling and heating coils while the SMECT and MFT have just cooling coils. SMECT cooling coils are constructed of S31603 stainless steel, while the other assemblies are constructed of alloy N10276.

Initial evaluation of the SME and MFT coils following Waste Qualification Runs, prior to Radioactive Operations showed significant localized erosion on the bottom inner coil run at support bracing, coil supports, and process supply piping that extends below the bottom coil loop directly impacted by frit slurry. In March 1997, the SME cooling coil failed due to erosion (i.e. penetration) in the cooling water supply pipe extending below the coil. The coil was removed from service and repaired using Stellite 6 (W73006) weld metal overlays on curved sections and ULTIMET alloy (R31233) plate wraps on straight pipe sections. The SME cooling coil again failed in March 1998. It was removed from the tank and replaced with a spare unit of similar design, although the bottom supply piping was redesigned to minimize the extent protruding below the bottom coils. The failed coil was
pressurized in a remote cell and visual evidence suggests that the lower cooling coil failed near a support. Replacement SME process coil assemblies are being procured which contain protective R31233 wear resistant pipe and fittings in areas sensitive to erosion.

Agitators - The SRAT, SME and MFT have agitator blade assemblies constructed of alloy N10276 which allow mixing of the sludge/slurry/frit mixtures. The agitators consists of two sets of blades - an upper set of three hydrofoil blades and a lower set of four rectangular blades.

Initial evaluation of the agitators following Waste Qualification Runs, prior to Radioactive Operations showed severe erosion on the backside of the SME and to a lesser extent the lower MFT agitator blades. The erosion was again caused by the abrasive frit slurry on the alloy N10276 base metal and may have been enhanced by the boiling cycles (i.e., bubble formation, etc.) in the SME. Prior to radioactive operations spare agitators were installed in both the SME and MFT which had been modified to add W73006 weld metal coatings to high wear areas on the backside of the lower agitator blades.

In March 1997, the SME agitator was removed and inspected. Severe erosive wear patterns were observed on the backside of the lower blades in areas not protected by the W73006 weld metal coatings. In addition, significant wear was also observed on the leading edges of the top hydrofoil blades (alloy N10276 construction). The SME agitator shaft assembly was further modified to add W73006 weld metal coatings to all uncovered areas on the backside of the lower agitator blades. No alterations to the top hydrofoil blades were made. The unit was placed back in service.

The SME agitator was again pulled for inspection in March 1998 after a total of two years of radioactive service and approximately 50 batches of slurry. It was replaced by a similar, although, unprotected, spare agitator assembly for short term service. During subsequent inspections of the failed agitator shaft, it was determined that the backside of the lower agitator blades that were protected by W73006 weld metal coatings appeared to be in excellent condition. The upper hydrofoil blades were heavily eroded from the leading edges, with thorough wall penetration on two of the blades. The hydrofoil blades were repaired using alloy N10276 weld metal. It is anticipated that the SME agitator will be placed back in-service during May 1998.

Future permanent design changes may allow fabrication of both the upper and lower SME (and MFT) agitator blades from alloy R31233. Limited bench scale testing suggests that this cobalt based alloy may provide optimum performance in regard to both corrosion and erosion.

Glass Level Detection

DWPF utilizes an infrared camera to determine glass level in a canister. Rectangular stainless steel targets are located in front of the canister. The dimensions and positioning of the targets relative to the canister are known. These
targets remain at the melt cell’s ambient temperature during canister filling. As the canister is filled its temperature increases from ambient to approximately 800°C. This provides color contrast and, thus, by noting the “line” of highest temperature across the diameter of the canister the glass level can be determined using the targets.

The infrared camera is utilized at the start of pouring and the last 4-5 hours of canister filling. The infrared level is used to report glass level to demonstrate compliance with the WAPS. A load cell that measures canister weight monitors canister filling throughout the pour process. The load cell provides a reliable method for tracking canister weight. However, an absolute measure of canister weight is difficult due to the following:

- A bellows attaches the canister to the pour spout. The average bellows force varies from 174 to 286 pounds.
- The expansion of the canister during filling increases the force on the bellows thus increasing apparent canister weight. The expansion force can vary from 15 to 350 pounds.
- The canister has a throat protector in place during filling which weighs about 11 pounds.

Work is currently underway to improve the reliability of weight measurements. This work involves setting up a program for routine calibration of the load cell and for checking the variations of the factors discussed above that affect weight. In addition, a program is already in place for monitoring canister weight against the glass level determined from the infrared camera.

LESSONS LEARNED

Startup Test Program

The DWPF Startup Test Program was modeled on the testing required for startup of a commercial nuclear reactor. The Startup Test Program:

- Demonstrated the DWPF's ability to reliably produce an acceptable product that meets the requirements of the WAPS. This was accomplished during the Waste Qualification Runs portion of the Startup Test Program.
- Demonstrated the operability, reliability, and integrity of the major process systems.
- Provided operating experience to operations, maintenance, and engineering personnel.
- Baselined equipment and system operating parameters.

The Startup Test Program was a formalized program that had senior management involvement. Senior management from the Operations, Engineering, Startup, and Quality Assurance organizations formed a Joint Test Group. The Joint Test Group approved all Startup Test Plans and Test Procedures. Acceptance criteria were well defined and documented in the test plans and procedures. The test procedures included standard operating procedures to allow operators to gain experience and refine procedures.
Early in the startup testing process a structured process for evaluating schedules and priorities was initiated. This process consisted of plan of the day or plan of the week meetings with upper management and other key personnel. Schedules were statused, roadblocks flagged, and priorities evaluated. These meetings continue today to retain focus on operational issues.

Milestone Preparations

It is important to perform a readiness self assessment (RSA) as close as possible to the operational readiness review (ORR) or have continuous self assessment to bridge time span. This will ensure the facility is ready. If possible it is also helpful to enlist peer review of site wide knowledgeable personnel to evaluate RSA and provide an independent review of the paperwork. Open items should be limited as much as practical as they only raise questions.

DWPF only underwent an ORR prior to the Radioactive Operations milestone. The Westinghouse Savannah River Company ORR was held first. This internal ORR needs to be tough. The team should limit observations and focus on providing detailed findings. The DOE ORR will review the internal ORR prior to starting their own review, thus, the more thorough the internal ORR the more smoothly the DOE ORR should progress.

A contact person should be named for each ORR team to provide focus and obtain information as requested. Upper level management needs to be involved in the process and any ORR team issues should be resolved as quickly as possible prior to the generation of a finding. It is also critical to have the facility ready for ORR. At DWPF certain facility modifications weren’t complete so DOE couldn’t observe process and emergency response actions. Thus, the DOE ORR had to stop their activities and come back again a couple of months later to finish the review.

For each major milestone (e.g. Waste Qualification Runs, Radioactive Operations) DWPF named a milestone manager to focus on the milestone. This individual tracked any open items to closure to ensure readiness for the milestone. Planning and scheduling are critical to meeting milestones and completing programs.

DWPF was fortunate to have continuity of key personnel in the various organizations. Cognizant engineers were designated for each system. These engineers were then responsible for the testing and operation of their systems.

CONCLUSIONS

DWPF has almost completed two years of radioactive waste vitrification. Three hundred canisters have been filled with radioactive waste glass. The experience gained during startup testing and radioactive operations can be extremely valuable for future operations at DWPF and other vitrification facilities.
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REFERENCES