The Defense Waste Processing Facility, from Vision to Reality

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Abstract

When the Savannah River Plant began operation in the early 1950s producing nuclear materials for the national defense, liquid, highly radioactive waste was generated as a byproduct. Since that time, the waste has been stored in large, carbon steel tanks that are buried underground. In 1960, one of the tanks developed a leak, and before recovery measures could be taken, about 25 gallons of radioactive salt solution overflowed the secondary liner and seeped into the soil surrounding the tank. Significant improvements to the tanks were made, but constant surveillance was still required. Thus, the opinion began forming that storing the mobile, highly radioactive waste in tanks was not a responsible long-term practice. So, in the late 1960s, the Savannah River Laboratory began research to find a suitable long-term solution to the waste disposal problem. Several alternative wasteforms were evaluated, and in 1972, the first Savannah River waste was vitrified on a laboratory scale.

Introduction

When the Savannah River Plant (SRP) began operation in the early 1950s, highly radioactive waste generated during the production of nuclear materials for defense needs was stored in large, nominally 1-million-gallon, underground storage tanks. This mode of storage, which had been the practice at SRP's sister facility, Hanford, in Richland, Washington, has been judged to be a safe and effective way to isolate the hazardous radionuclides from the environment. However, in 1960, one of the tanks developed a leak, and, before recovery measures could be taken, about 25 gallons of radioactive salt solution had overflowed the secondary liner and seeped into the soil surrounding the tank. Although improvements to the waste storage tanks were made, including extending the height of the secondary liner to the top of the tank, constant surveillance was still required. Thus, the opinion began forming that storage of the mobile, highly radioactive liquid waste in tanks was not a responsible long-term practice.

In the late 1960s, the Savannah River Laboratory (SRL) began research to find a suitable solution to the waste disposal problem. Several alternative wasteforms were evaluated in terms of product quality and fabrication reliability. And, in 1972, SRL first vitrified actual Savannah River waste on a laboratory scale. Previously, Pacific Northwest Laboratory had studied waste vitrification since the early 1960s, and they provided substantial support during early development efforts at SRL.

By the mid-1970s, the Du Pont Company, then prime contractor at the Department of Energy's (DOE) Savannah River Plant, began to develop a vision of constructing America's first vitrification plant to immobilize the high-level radioactive waste stored in the SRP waste tank farms in borosilicate glass. This vision was later championed by Du Pont as a vitrification plant called the Defense Waste Processing Facility (DWPF). This plant was viewed with conviction as a timely step to close the nuclear fuel cycle and assist in developing a national nuclear waste disposal policy. Today, the DWPF processes Savannah River High Level Waste (HLW) sludge, turning it into a solid, durable wasteform of borosilicate glass. The DWPF is the world's largest vitrification facility, brought to reality through over 25 years of research and 13 years of careful construction, tests, and reviews at a cost of approximately $3 billion dollars.

The Vision

The vision embraced by Du Pont to immobilize SRP's highly radioactive liquid waste in borosilicate glass was an ambitious one. In the late 1970s, the Department of Energy recognized that there were significant safety and cost advantages associated with immobilizing the high-level waste in a stable solid form. However, at the time, there was not a consensus among leaders in the nuclear community regarding the wasteform or the process. Wasteforms had been studied since the 1960s, and, in the 1970s, a national and international consensus towards borosilicate glass was building. To reach a conclusion, the early studies were expanded and formalized to evaluate about 20 different wasteforms, including synthetic rock, tailored ceramics, glasses, and cement. This research confirmed that the radioactive species in the waste were bound chemically in the borosilicate glass matrix, making it a very durable wasteform. By 1979 borosilicate glass was clearly emerging as the top wasteform, based on an optimum combination of cost to produce, risk to people and the environment, and likely public acceptance it provided. France had selected borosilicate glass as the wasteform for a plant at Marcoule to immobilize high-level waste. England, Germany, and Japan were seriously considering this wasteform for immobilizing their high-level radioactive waste. Early in 1982, the choice of borosilicate glass for disposal of SR high-level waste (HLW) was endorsed by independent consultants engaged by Du Pont and the Department of Energy.

Although safety and protection of the environment were substantial drivers for the DWPF facility, the high cost of the storage tanks was an additional, and very tangible, incentive to construct the DWPF as soon as possible. After years of research, the wheels were set in motion in December 1981, when E. G. Jefferson, chairman of the Board of the Du Pont Company, in a letter to Edwin Meese, Counselor to the President, urged the Administration to support project funding. In accordance with the NEPA (National Environmental Policy Act) process, an Environmental Impact Statement was prepared for the facility, as well as an Environmental Assessment of the alternative wasteforms, and a Record of Decision (in December 1982) on the wasteform was issued. This Record of Decision was endorsed by the Environmental Protection Agency and several independent review groups. The Nuclear Regulatory Commission (NRC) also reviewed the document and offered no objection.

Early efforts by SRL to further develop the emerging technology focused on engineering calculations to define an integrated conceptual flowsheet, wasteform development to optimize processing and durability characteristics, and melter development. Experiments to define and demonstrate processes to prepare the waste for vitrification and to treat the offgas from the melter soon followed. The development and demonstration of the DWPF process was accomplished on a small scale in SRL's shielded cells, using actual waste and on a large scale using simulants in pilot facilities. Summarizing these developments, the first Technical Data Summary for the DWPF was issued in August 1978. The accompanying flowsheet was much different than the process we see operating today, demonstrating how the process has evolved.

Evolution of the DWPF Process

From the days of its inception until a few months before radioactive startup, the DWPF process evolved in response to the need for cost reductions, discoveries during development, and safety problems in the supernate pretreatment process. It is a tribute to the commitment and innovation of the entire team that supported and operated the DWPF that these changes, particularly those occurring after non-radioactive commissioning tests began, were accomplished with minimum impact to the vitrification mission.

The DWPF process was designed for Savannah River HLW, generated during processing fuels from the Site's nuclear reactors. Over 30 million gallons of the waste is stored in 51 carbon steel tanks in the form of settled sludge and saltcake. Neutralized to inhibit corrosion of the tanks, the waste contains a large fraction of non-radioactive chemicals and nearly every element in the periodic table. Because of this, the DWPF more resembles a complex chemical process than a nuclear process. To minimize costs, the overall strategy for vitrification of Savannah River HLW has always been to separate most of the non-radioactive salts from the radioactive constituents and dispose of this material in a less expensive manner than vitrification.

In the earliest flowsheets, the DWPF received a single, blended waste stream consisting of insoluble solids (sludge) and soluble salts (supernate). The sludge is the principal concern because it contains over 60% of the total radioactivity and essentially all of the long-lived radionuclides, which present over 90% of the hazard to man. The sludge was to be washed with water and centrifuged in the DWPF. The salts from the sludge were then to be combined with the supernate.

Although by weight the supernate is almost all non-radioactive salt, it contains most of the cesium in the HLW, and traces of strontium, which are highly radioactive. In the early flowsheets, these contaminants were to be removed by ion exchange and the decontaminated supernate was to be sent back to the Tank Farms to be evaporated to semi-dry saltcake and stored in decommissioned waste tanks. The radioactive stream from ion exchange was to be combined with the washed sludge and vitrified. The glass would be cast and sealed in stainless steel canisters and stored in a building onsite until a federal repository became available. This proposed process would immobilize the 30 million gallons of HLW in approximately 1 million gallons of glass, containing essentially all of the radioactivity, and several million gallons of decontaminated saltcake. Refinements to this early process were made, but the cost estimate, at $4 billion, was more than Congress would appropriate. The challenge was to cut the cost to less than $1 billion.

Serious efforts were therefore begun to reduce the cost and increase funding flexibility for the facility. Blending the sludge and salt streams in the Tank Farms was eliminated and two separate streams, salt and sludge, were sent to two separate DWPF facilities that could be funded in stages. An ion exchange facility decontaminated the salt stream, and a vitrification facility immobilized the radionuclides. Also, the cost of vitrification was significantly reduced by changing from two calciner-melter trains to one slurry-fed melter. But further cost reductions were needed, and research and design improvements provided opportunities.

The Melter

The melter, the heart of the vitrification process, was selected via evaluation of several different options. Considered the most unproven portion of the required technology, an emphasis was placed on melter development from the beginning. The first choice was a joule-heated ceramic melter. U.S. developers, Germany, and Japan favored this type melter over the inductively heated Inconel melter used by the French because of longer melter life and improved control of product composition. Du Pont had experience with high temperature, refractory lined reactors, making them cylindrical to increase reactor life. The first melter was therefore designed in a similar manner, and that design was not altered throughout development. This was a departure from the less expensive rectangular melters tested at other sites in the U.S. and Germany. The optimum materials of construction were identified early to be Monofrax K-3 refractory and Inconel 690 electrodes, heaters, and piping.

In August of 1980, SRL started up the first DWPF pilot melter. The design incorporated a spray calciner coupled atop the melter and top-entering electrodes to heat the glass via the joule effect. Horizontal resistance heaters in the vapor space initially heated a glass charge to the point that it would conduct joule current from the electrodes and to provide additional heat to boost the melt rate during production. Early testing, however, foreshadowed difficulty with remotely operating a spray calciner. This, and a substantial cost saving that could be realized by removing the calciner and decreasing the building height, prompted consideration of a change to an innovative process being studied by the Germans, feeding the waste and frit directly to the melter where evaporation, calcination and melting would take place. This was called the Slurry-Fed Melter.

At about the same time, an alternative process, the In-Can Melter, in which a waste/frit slurry was fed directly into a storage canister and melted by an induction heater was considered. Both the In-Can Melter and Slurry-Fed Melter were tested in pilot scale, and while the In-Can process had several advantages, including simplicity, it presented a problem in ensuring uniform glass quality. The slurry-fed melting process proved viable, however, and was therefore taken forward as the new design basis.

Several half-scale pilot melters were tested at TNX, SRL's semi-works facility, using simulated waste, as were several small-scale melters. A small joule-heated melter was also installed in SRL's shielded cells where actual waste samples were vitrified. Several unique design features were demonstrated through testing on these melters, including pouring by creating a vacuum in the cansiter and cooling the offgas via a device named an Offgas Film Cooler. The Offgas Film Cooler, invented by SRL and designed by the Du Pont Engineering Department, prevented pluggage of the offgas line exiting the melter, and is now used worldwide on slurry-fed melters. Pneumatic agitation to boost the melt rate was also tested in pilot melters. However, bubbler life was short due to corrosion and/or errosion by the hot glass, and agitation was abandoned.

Later, a one-tenth-scale pilot melter was built to test a more complete simulation of the waste, including mercury and noble metals. This melter, called the Integrated DWPF Melter System, or IDMS, was fitted with full feed preparation and offgas systems, which were constructed of design basis materials for corrosion evaluation. IDMS's primary mission, however, was to determine the fate of noble metals in the system, which tend to precipitate, creating a conductive path that would short the joule electrodes. In total, research melters at SRL, now called the Savannah River Technology Center (SRTC), poured over a million pounds of glass while refining and demonstrating the DWPF melter design and the DWPF process.

Supernate Decontamination

Removing the radionuclides from the salt component of the waste, however, proved to be a greater challenge than vitrification of the sludge. The original process employing ion exchange required a large canyon building (slightly larger than the vitrification plant). Commercially available elutable ion exchange resins were first proposed. With these, the cesium in the eluate had to, in turn, be loaded onto a zeolite for combination with the sludge due to the large eluate volume and lack of compatibility with the vitrification process. Because the facility was first estimated at over $1 billion, all development efforts were focused on reducing the size and cost of the canyon. Several improved resins were evaluated, and new resins were developed. A resorcinol-formaldehyde resin with significantly improved properties was one of the new resins. This resin reduced the size of the columns and the canyon, but the process was still very expensive.

A breakthrough occurred when a precipitation process using sodium tetraphenyl borate to precipitate cesium was developed. Because this process had potential to be implemented in existing waste tanks, it could provide savings on the order of $800 million. The process, called In-Tank Precipitation, was successfully demonstrated in an actual waste tank in 1983 and adopted as the preferred process. This was the breakthrough needed; accumulating all the cost savings, the estimate for the vitrification plant came in at just under $1 billion, and the DWPF project was funded.

However, in 1995 when the In-Tank Precipitation facility was started up, a larger-than-expected benzene release was observed. Extensive studies showed that a temperature-sensitive catalytic decomposition of the main reactant, tetraphenylborate, was responsible for release of the flammable benzene. Because the In-Tank Precipitation facility could not cost effectively meet the safety and production requirements for the high-level waste system, Westinghouse Savannah River Company (WSRC) suspended operations, and a study was initiated to evaluate alternative processing options.

DWPF, however, was designed with sufficient flexibility that the vitrification process could operated on flowsheets processing sludge only, sludge and salt, or salt only. DWPF is currently running a “sludge-only” flowsheet, bypassing the cell that hydrolyzes the tetraphenylborate precipitate to remove benzene for more efficient melter operation.

A Quality Product

Meanwhile, the development of the borosilicate glass product continued, as did the development of the regulations governing its quality. The Nuclear Waste Policy Act of 1982 mandated that all high-level waste would be sent to a federal repository for disposal. In 1985, the president ratified a decision made by the Secretary of Energy to send defense high-level waste, including the canistered wasteforms (stainless steel canisters filled with borosilicate waste glass) from the DWPF, to a civilian repository. The Department of Energy, recognizing that start-up of the DWPF would considerably precede licensing of a repository, instituted a Waste Acceptance Process to ensure that these canistered wasteforms could be accepted for eventual disposal at a federal repository.

Representatives from the repository projects and the wasteform producers developed preliminary waste acceptance specifications that identified requirements for the canistered waste forms. These early specifications were initially developed by SRTC and HLWM management personnel in support of DOE. The specifications eventually evolved into the Waste Acceptance Product Specifications for Vitrified High-Level Wasteforms (WAPS).

The WAPS require the DWPF glass wasteform to be more durable than an environmental assesment glass as measured by the product consistency test (PCT). The PCT involves placing crushed glass in sealed vessels filled with water for 7 days at 90°C. The leachate is then analyzed for the elements B, Na, and Li to determine the glass durability. These elements have been shown to bound the leach rate of the radionuclides.

Since DWPF does not have the ability to recycle unacceptable glass, and it is impractical to hold up the process for a 7-day test, it is desirable to control the process prior to vitrification. The DWPF ensures an acceptable glass product by controlling the melter feed composition. A correlation between composition and PCT results has been developed for use in control of the vitrification process. In addition to controlling the glass durability, as measured by the PCT results, it is necessary to ensure that the glass viscosity and glass liquidus temperature are within acceptable ranges. Correlations between these glass properties and composition have also been developed. These glass property correlations are embedded in the Product Composition Control System (PCCS) along with statistical algorithms to appropriately account for measurement error. The PCCS is the tool used by DWPF engineers to judge acceptability of the melter feed in each batch. Feed batches will be transferred to the melter only after there is confidence that they will produce acceptable glass. Occasionally a glass pour stream sample is taken to confirm acceptability.

Construction

Construction of the DWPF was no small feat of accomplishment. For protection of workers from radiation and contamination hazards associated with the HLW, and for protection for the public in the event of accident or natural disaster, the DWPF process is contained within a reinforced concrete building with 3-foot-thick walls. Processing cells within the building also have 3-foot-thick walls, and operations are conducted remotely. A robust ventilation system with redundant fans and emergency power ensures that air flows within the building are from clean, occupied areas into areas containing the process and are exhausted through a giant, underground sand filter outside the process building. Filters within the facility combined with the sand filter remove essentially all radioactivity in the ventilation air, even in the event of the worst imagined accident scenarios. Designed by Bechtel and constructed by Morrison Knudsen, the DWPF was built to withstand earthquakes and tornadoes with a functional lifetime well in excess of the 20 to 25 years required to immobilize all the HLW stored at the Savannah River Site. The facility contains 71,000 cubic yards of concrete and 10,500 tons of reinforcing steel. The 10-foot-thick concrete foundation mat is reinforced by 2-1/4-inch diameter reinforcing steel.

Groundbreaking for the DWPF occurred in 1983. Estimates in 1985 forecast project completion for September 1989, and radioactive startup in January 1990. However, as discussed later, radioactive startup was not to be until March 1996. Perhaps the greatest difference in the adjusted schedule and this early schedule lay in the time required for commissioning. The complexity of regulations and the degree of rigor required in commissioning combined with technical and engineering challenges to extended commissioning from a few months to a 5-year activity.

Startup Testing

Prior to the start of Radioactive Operations in 1996, DWPF underwent an extensive Startup Test Program. This test program consisted of Integrated Water Runs, Chemical Runs, Waste Qualification Runs, and Proficiency Runs. On a tight schedule, DWPF began functional checkout as sections of the plant were turned over to Operations. Integrated Water Runs, which tested piping and equipment up to the melter, were completed in 1992. During Cold Chemical Runs, simulated feeds and raw materials were introduced into the facility and the first batch of melter feed was produced. Melter heatup, 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 the range of waste compositions expected. Simulated waste was transferred into the DWPF and processed using the same methods to be used for radioactive waste. Fifty-five canisters were produced during these tests, and the glass and canistered wasteforms produced were extensively characterized. The results of this characterization were the principal data that demonstrated the DWPF's ability to comply with the WAPS. In total, 80 canisters of simulated glass were produced during the Startup Test Program.

Following Waste Qualification Runs, Proficiency Runs were completed in which two batches of melter feed were produced performing all operations as though the feed was radioactive. The WSRC Operational Readiness Review (ORR) was completed, followed by the DOE ORR, and in March 1996 the DWPF was ready for Radioactive Operations. That month the first transfer of radioactive sludge arrived in the DWPF canyon building. The sludge was prepared according to well practiced procedure, and the glass frit was added. After concentration it was moved into the melter, and the first radioactive glass was poured into a canister. Canister decontamination and closure welding were completed, and the first canister of Savannah River HLW glass was moved in the Glass Waste Storage Building in May 1996.

A Worldwide Milestone, a Vision Realized

Early in the year 2000, DWPF is processing the second waste tank (macro-batch) of radioactive sludge. The first macro-batch yielded 495 canisters from 420,000 gallons of sludge. In January 2000, almost four years after beginning processing, the world's largest radioactive waste vitrification facility produced its 3 millionth pound of waste glass product, which is a new production milestone worldwide. Thus, the vision of building a plant to safely immobilize Savannah River high-level waste has clearly been realized. With the continued commitment of the Department of Energy and the Westinghouse Savannah River Company, the legacy of the remaining HLW at Savannah River will be processed into a stable borosilicate glass wasteform by 2028.

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