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EXAMINATION OF DWPF MELTER MATERIALS AFTER 8 YEARS OF SERVICE

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ABSTRACT

The first Defense Waste Processing Facility high level radioactive waste glass melter was successfully operated for eight years. Recent failure of melter heaters and decrease in glass production necessitated its removal. Prior to removing the melter from the facility, a remote in situ visual inspection of the refractory and Inconel™ 690 components was performed. The vapor space and glass contact refractory blocks were in excellent condition, showing little evidence of spalling or corrosion. Inconel 690 top head components and lid heaters in the vapor space were also in good condition, considering the service. Upper electrodes experienced significant deflection, which probably resulted from extended operation in excess of 1150 °C. Condition of the melter components examined during the remote visual inspection is summarized in this paper.

BACKGROUND

Operating History

Approximately 136 million liters (36 million gallons) of highly radioactive liquid waste from the production of nuclear materials at the United States Department of Energy's Savannah River Site (SRS) are presently stored in large underground carbon steel tanks. SRS is currently in the process of tank farm closure and is dispositioning the inventory of high level waste. One of the technologies developed at SRS for immobilizing the waste to allow for controlled decay of long-lived radionuclides is vitrification. The process begins with the transfer of liquid high level waste sludge to the Defense Waste Processing Facility (DWPF) where the chemistry is adjusted by addition of nitric and formic acids. Borosilicate frit is then added and the slurry is concentrated until a solids content of 45 to 50 wt% is attained. The slurry is finally fed to a melter where it is melted. The resultant high level waste glass is poured into stainless steel canisters, which are subsequently sealed.

DWPF's first glass melter began operation in May 1994 and was shut down for replacement in November 2002. It operated continuously for over eight years, including 2 years of non-radioactive cold chemical operations followed by 6 years of radioactive waste processing. Over 1400 canisters, 2.4 X 10^6 kg (5.2 million pounds) of glass, have been successfully poured. This represents about 27 percent of the total glass to be produced in this facility.

The DWPF Melter (Figure 1) is a refractory lined cylindrical vessel. Heat is provided via Joule heating of the glass and by resistance heaters located in the melter plenum, riser, pour spout, and drain valve. Internal dimensions are approximately 1.83 m (6 ft) diameter by 2.2 m (7 ft) high. Nominal glass depth is 86 cm (34 in). Glass contact material is Monofrax™ K-3, a fused-cast chromia-alumina refractory. Vapor space refractory is Korundal™ XD. Metal components in contact with the glass and vapor space are Inconel™ 690. These include thermowells, a bubbler, off gas film coolers, lid heaters, borescopes, and electrodes.

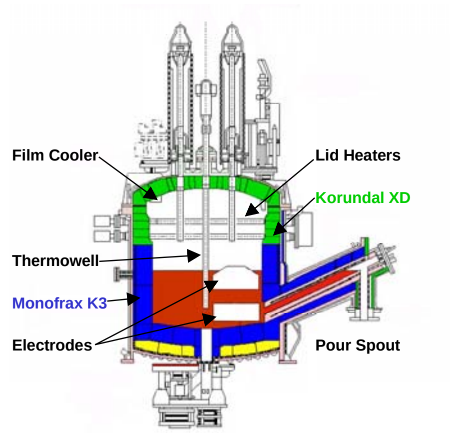


Figure 1. Schematic of the DWPF melter.

The melter was operated at a glass temperature of 1050 to 1200 °C. Lid heaters were maintained at 975 °C, which kept the vapor space at 500 to 900 °C during feeding and idle conditions, respectively. An air purge of 204 kg/hr (450 lb/hr) was maintained into the plenum to promote combustion of organics in the feed. Glass production rates varied from 36 to 91 kg/hr (80 to 200 lbs/hr). Nominal high level waste melter feed composition is shown in Table 1.

Figure 2. Film cooler suspended by canyon crane. Inlet (bottom) shows minor attack.

Prior Inspections

Following completion of cold chemical runs in 1996, an extensive visual inspection of melter top head and off gas components was performed. The inspection focused on vapor space and molten glass attack. No significant degradation was observed, except for the chloride salt attack and oxidation of the borescope (Ref. 1) and minor oxidation of the tip of the off gas film cooler (Figure 2).

During early radioactive operation, glass pouring problems led to remote visual inspection of the melter pour spout. This was accomplished by the use of a high temperature remotely operated borescope. Examination revealed significant material loss on the glass contact side of the pour spout (Figure 3). This figure

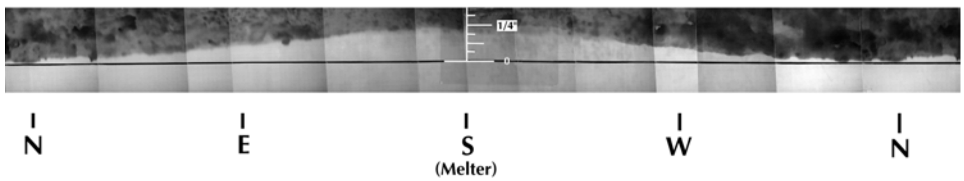


Figure 3. Panoramic view of the Inconel 690 pour spout showing 6.4 mm (0.25 in) metal loss on the glass disengagement point (S)

represents a 360 degree panoramic view of the pour spout bore, showing the extent of material loss, estimated to be 6.4 mm (0.25 in) at the glass disengagement point at that time. The need to reestablish desired glass flow characteristics led to the development of a remotely deployed replaceable pour spout insert. Subsequent metallurgical examination of a degraded insert established a nominal corrosion rate 4.78 mm/yr (0.188 in/yr) and the mechanism for the observed attack (Ref. 2).

Table I. Nominal Melter Feed Composition

Analyses			Analyses		
Total Solids	48.40	wt%	Calcium	0.998	wt%
Calcined Solids	43.64	wt%	Chromium	0.065	wt%
Density	1.395	g/mL	Copper	0.022	wt%
pH	6.8		Iron	8.815	wt%
TOC	8401	ppm	Potassium	0.136	wt%
Formate	26792	ppm	Lithium	1.492	wt%
Chloride	< 1,050	ppm	Magnesium	1.419	wt%
Fluoride	< 1,050	ppm	Manganese	1.172	wt%
Nitrate	12391	ppm	Sodium	8.010	wt%
Nitrite	< 1,050	ppm	Nickel	0.438	wt%
Phosphate	< 1,050	ppm	Silicon	22.911	wt%
Sulfate	< 1,052	ppm	Titanium	0.036	wt%
Aluminum	2.454	wt%	Uranium	2.999	wt%
Boron	2.325	wt%	Zirconium	0.073	wt%

The melter center thermowell was removed in May 2000 and visually inspected. It experienced slight melt line attack, but otherwise appeared to be in good condition. The Inconel 690 dip tube bubbler melt level detection device was removed in April 2002 after approximately seven years of service. It originally had a 7.62 cm (3 in) outer diameter with a 1.27 cm (0.5 in) diameter center bored hole through which argon was bubbled at 0.014 to 0.028 m^3/hr (0.5 to 1 scfh). Remote video inspection revealed that through wall attack had occurred on one side over approximately 76.2 cm (30 in) of the submerged length ending just below the melt line (Figure 4). This relatively high rate of material loss can be attributed to the "scrubbing" effect of continuous bubbling. A portion of the tip, approximately 15 cm (6 in), was completely lost.

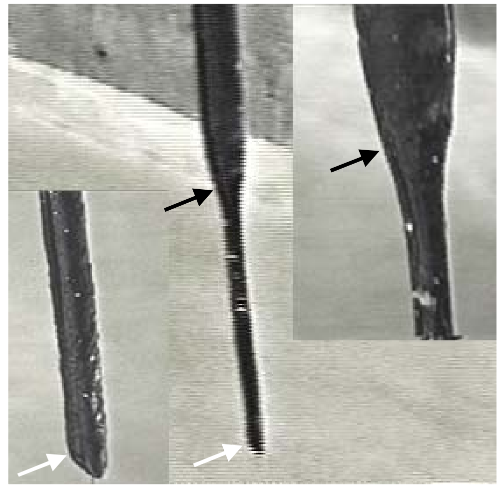


Figure 4. Photograph of bubbler showing necking at melt line and through wall attack between arrows.

Near the end of melter life the zone, 1 drain valve heater failed. This strip heater was fabricated from Inconel 690. The component could not be inspected after failure, so the reason for failure is unknown.

Melter End Of Life Inspection

Following melter shut down, an inspection was performed using a remotely deployed video camera suspended 12.2 m (40 ft) below the facility remote operated crane (Figure 5). This camera, called Mini-Sputnik, is a remotely controlled, video-based viewing system developed at SRS for inspecting tanks, vessels, and other difficult to access areas in the DWPF Canyon. The system was designed to be deployed in a vessel through a 6.4 cm (2.5 in) opening to a depth of 1.83 m (6 ft) using the canyon crane. An operator in the crane control room controls all system functions

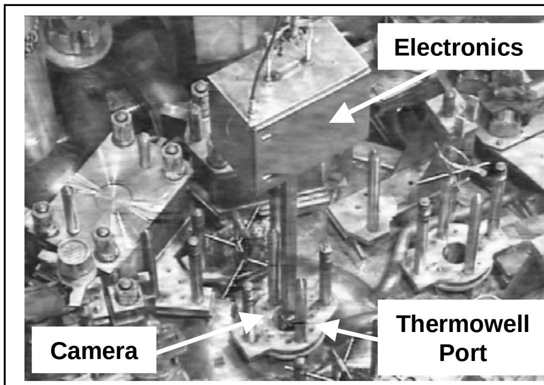


Figure 5. Mini-Sputnik being lowered through the center thermowell port on the melter.

including lights, pan-tilt-zoom and focus. Because the system is NTSC video based, resolution was limited.

Refractory Materials

The glass contact refractory, Monofrax™ K-3, was in excellent condition. Minimal spalling was observed in several localized regions around the melt line. It was significantly less than that observed in pilot scale melters. Refractory attack was expected to be greatest in the vicinity of the melt line, but only minimal corrosive attack was observed (Figure 6 and 7). Corners of the refractory blocks exhibited some rounding; however, the joints were still square indicating that no significant shifting of the refractory blocks had occurred. Gross material loss was low. This qualitative observation was based on relative distance between the back face of the upper electrodes and the refractory wall. This represents a refractory corrosion rate significantly lower than that predicted by the initial pilot scale work. Melter design life was 2 years based on the pilot scale work and a corrosion allowance of 4 inches of refractory. The present results are better than those seen in the Large Slurry Fed Melter and Scale Glass Melter at SRS (Ref. 3).

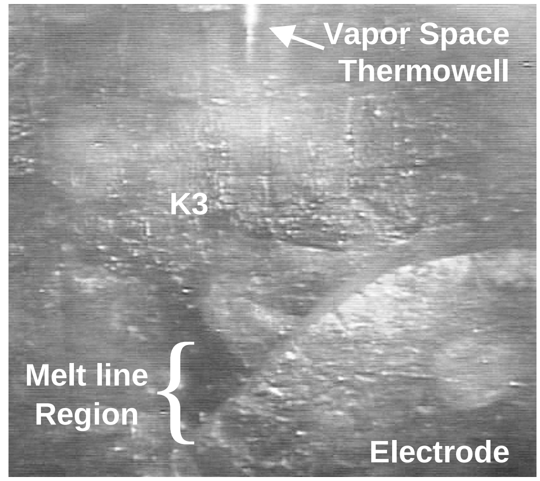


Figure 6. Photo showing condition of K3 blocks near melt line.

The vapor space refractory, Korundal™ XD, was in excellent condition (Figure 7). No missing pieces or shifted blocks were seen. No signs of chipping or spalling were observed around the top head penetrations or dome heaters. The entire refractory surface was glazed.

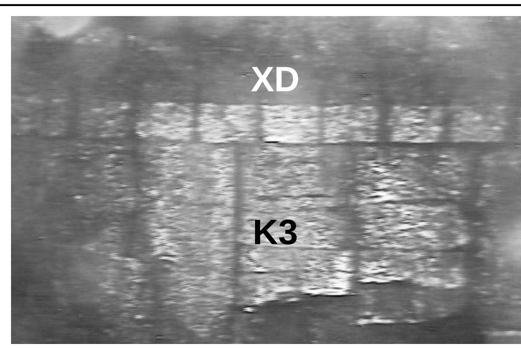
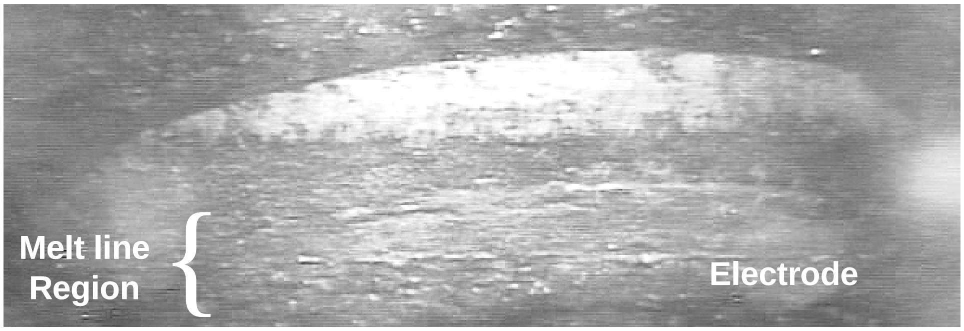


Figure 7. Photograph of Korundal XD refractory in the vapor space.

Inconel 690 Components

The lower electrodes were not visible due to residual glass in the melter. Upper electrodes were completely visible and exhibited rounding of corners and edges below the melt line and an obvious downward deflection (Figure 8). The



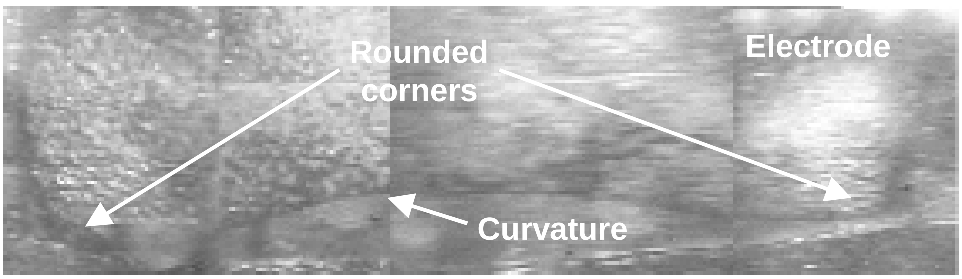


Figure 8. Upper electrode, Top photo: Upper portion showing downward deflection. Bottom photo: Composite showing curvature and rounding of corners on the bottom portion.

deflection was probably a result of creep. The faces of the electrodes exhibited an irregular surface morphology; however, it was not clear whether it was due to localized material loss or build-up of deposits.

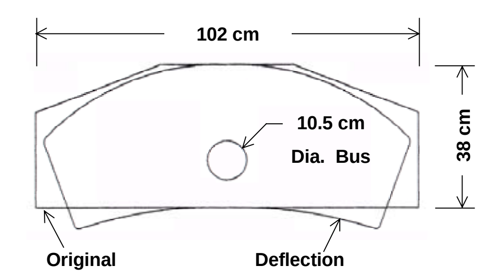


Figure 9. Schematic of the upper electrode showing the original shape and the observed deflection.

The upper electrodes were originally 101.6 cm (40 in) wide by 38.1 cm (15 in) high by 7.62 cm (3 in) thick. The 215.5 kg (475 lb) electrode was supported by a centrally located 10.2 cm (4 in) diameter bus and was mounted flush against the refractory wall. Downward deflection of the ends was significant and was symmetric around the bus (Figure 9). Initially it was thought that the observed shape was due to material loss resulting from corrosion. A more detailed examination revealed that the shape was due to deflection rather than corrosion. This is based on the following:

1) Normal corrosion mechanisms cannot explain the concave shape of the bottom of the electrode.

2) The upper portion shows curvature, yet the edges appear sharp suggesting they were not significantly corroded.
3) The overall appearance suggests uniform symmetric slumping about the axis of the electrode bus. The appearance is similar to that expected under high creep rate conditions.

Existing high temperature creep data (Ref. 4, 5) show that at DWPF operating temperatures significant slumping is not expected. However, these data were generated using materials that had not been exposed to melter environments or at extended times (years). A change in mechanical properties due to long term elevated temperature exposure may explain the observed deflection. This supposition is based on an earlier metallurgical examination of the Inconel 690 drain valve exposed to 1150 °C glass for 7 years in the Integrated DWPF Melter System (IDMS). An extensive change in morphology was noted, including internal void formation, extremely large grains, and precipitates on grain boundaries through the entire microstructure (Figure 10). Electrode temperature may also have been a factor. This is based on modeling, which shows that higher

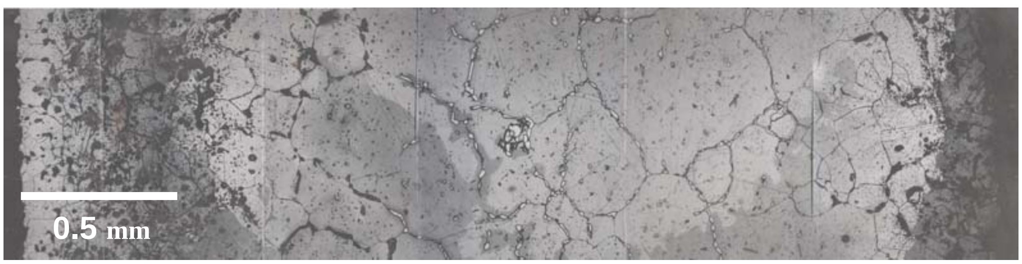


Figure 10. Photomicrograph showing the microstructure of an Inconel 690 through-wall section of the IDMS drain valve.

temperatures can be expected at the electrode face than in the bulk glass. Another factor is that the DWPF melter was at times operated up to 50 °C higher than the 1150 °C design temperature. (The melting point of Inconel 690 is 1345 °C.)

Off Gas Film Coolers

Both the primary and backup off gas film coolers were in good condition (Figure 11). Heavy deposits were observed on the tips that penetrated into the plenum but the contour of the lower lip was still visible. A small separation in a weld along the lower edge of the backup film cooler was observed. In the IDMS, a one tenth scale pilot melter, the film cooler was replaced after approximately 6 years of operation because several inches of material from the lower portion were lost.

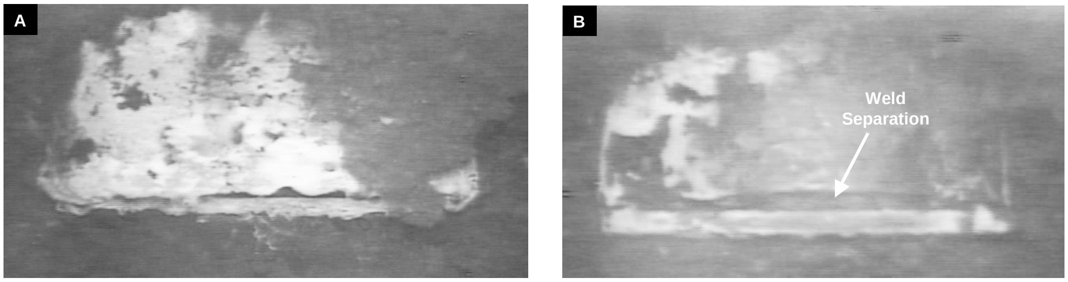


Figure 11. Primary (A) and backup film coolers (B). Weld separation on the lower lip of backup film cooler is evident.

Thermowells

The vapor space thermowell was in excellent condition, with no visual evidence of degradation even at the refractory/plenum interface (Figure 12). The side thermowell, which was partially immersed in the melt pool, experienced necking and loss of material as a result of exposure to the molten glass. This thermowell was still functioning after 6 years of service. This component was replaced prior to the beginning of radioactive operations.

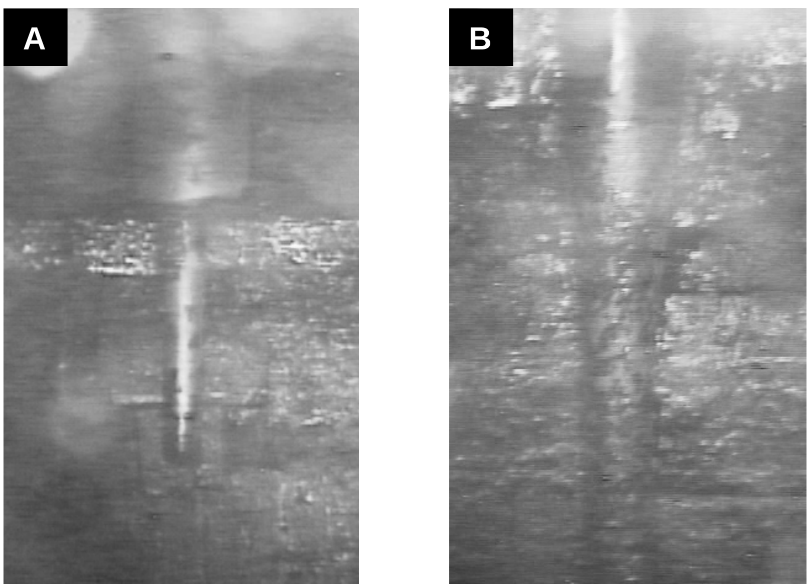


Figure 12. Vapor space (A) and side (B) thermowells. Molten glass attack in the immersion zone did not affect operability of side thermowell after six years of service.

Lid Heaters

The melter lid heaters (vapor space heaters) consist of eight resistance heated Inconel 690 tubes. They are 8.3 cm (3-1/4 in) OD by 1.27 cm (1/2 in) wall by approximately 1.65 m long (Figure 13). One of the heaters had failed (stopped passing current) prior to melter shutdown but the cause of failure was not evident during the inspection. Aside from that failure, the condition of the heaters was better than expected. They showed only minor deflection (upward in some cases) and no evidence of significant corrosive attack (Figure 13). This is supported by the operational history, which did not indicate a significant change in heater resistance over time. Slight upward bowing of the tubes may be attributed to differential thermal expansion between the refractory wall and the outer supporting cooled melter shell. Significant feedstock deposits were noted at the ends of the heaters. However, no evidence of hot spots or other damage was associated with the buildup. It is felt that the overall good condition of the heaters can be attributed to careful control of heater temperature during operations.

CONCLUSIONS

Based on the results of the remote visual inspection of the DWPF melter following eight years of operations it is concluded that:

- Overall, the melter was in better condition than expected based on earlier pilot melter studies.
- Loss of refractory due to spalling and corrosion was minimal.
- Corrosion of Inconel 690 components was no more severe than predicted by pilot scale melter and laboratory experience.
- Lid heaters showed no significant degradation or deflection.
- It could not be determined why one of the four lid heater circuits had failed.
- Dip tube bubbler showed significant degradation, which was attributed to “scrubbing” effect.
- Significant deflection of the upper electrodes was observed. This may be attributed to changes in material properties and operating at temperatures approaching the melting point of the material, 1345 °C. Risk of damage to Inconel 690 components is increased with increasing temperature above 1150°C.

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