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Feasibility Evaluation and Retrofit Plan for Cold Crucible Induction Melter Deployment in the Defense Waste Processing Facility at Savannah River Site - 8118

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ABSTRACT

Cold crucible induction melters (CCIM) have been proposed as an alternative technology for waste glass melting at the Defense Waste Processing Facility (DWPF) at Savannah River Site (SRS) as well as for other waste vitrification facilities. Proponents of this technology cite high temperature operation, high tolerance for noble metals and aluminum, high waste loading, high throughput capacity, and low equipment cost as the advantages over existing Joule Heated Melter (JHM) technology.

The CCIM uses induction heating to maintain molten glass at high temperature. A water-cooled helical induction coil is connected to an AC current supply, typically operating at frequencies from 100 KHz to 5 MHz. The oscillating magnetic field generated by the oscillating current flow through the coil induces eddy currents in conductive materials within the coil. Those oscillating eddy currents, in turn, generate heat in the material. In the CCIM, the induction coil surrounds a "Cold Crucible" which is formed by metal tubes, typically copper or stainless steel. The tubes are constructed such that the magnetic field does not couple with the crucible. Therefore, the field generated by the induction coil couples primarily with the conductive medium (hot glass) within. The crucible tubes are water cooled to maintain their temperature between 100^{o} C to 200^{o} C so that a protective layer of molten glass and/or batch material, referred to as a "skull", forms between them and the hot, corrosive melt. Because the protective skull is the only material directly in contact with the molten glass, the CCIM doesn't have the temperature limitations of traditional refractory lined JHM. It can be operated at melt temperatures in excess of 2000^{o}C, allowing processing of high waste loading batches and difficult-to-melt compounds. The CCIM is poured through a bottom drain, typically through a water-cooled slide valve that starts and stops the pour stream. To promote uniform temperature distribution and increase heat transfer to the slurry fed High Level Waste (HLW) sludge, the CCIM may be equipped with bubblers and/or water cooled mechanical agitators.

The DWPF could benefit from use of CCIM technology, especially in light of our latest projections of waste volume to be vitrified. Increased waste loading and increased throughput could result in substantial life cycle cost reduction. In order to significantly surpass the waste throughput capability of the currently installed JHM, it may be necessary to install two 950 mm CCIMs in the DWPF Melt Cell. A cursory evaluation of system design requirements and modifications to the facility that may be required to support installation and operation of two 950 mm CCIMs was performed. Based on this evaluation, it appears technically feasible to position two CCIMs in the Melt Cell of the DWPF within the existing footprint of the current melter. Interfaces with support systems and controls including Melter Feed, Power, Melter Cooling Water, Melter Off-gas, and Canister Operations must be designed to support dual CCIM operations. This paper describes the CCIM technology and identifies technical challenges that must be addressed in order to implement CCIMs in the DWPF.

INTRODUCTION

The DWPF has utilized a JHM to vitrify HLW since radioactive operations began in 1996. After processing over 5.2 million pounds of radioactive glass, equal to over 1.5 million pounds of vitrified waste, Melter 1 was removed from service in November 2002. Melter 2 was installed and brought on-line in March 2003. Since that time, Melter 2 has processed over 4.3 million pounds of radioactive glass, equal to over 1.6 million pounds of vitrified waste. However, to ensure tank closure by 2028, it is necessary to increase the waste vitrification rate through the DWPF. By optimizing waste loading and glass melt rate, the waste vitrification rate may be maximized for a given operating temperature. The DWPF JHM is limited by its materials of construction to operate near 1175°C. Given the CCIMs ability to operate at temperatures in excess of 2000°C, both waste loading and glass melt rate may be increased, significantly increasing waste throughput and providing a method of meeting the 2028 closure date.

Through a collaborative program between AREVA, the French Atomic Energy Commission (CEA), Savannah River National Laboratory (SRNL), and Washington Savannah River Company (WSRC), demonstrations using a 650 mm diameter CCIM at the Marcoule, France test site were formulated. The objectives were to 1) demonstrate the feasibility of processing a representative DWPF sludge surrogate that would 2) meet waste acceptance specifications while 3) achieving improved waste vitrification rates compared with the DWPF JHM. The DWPF most recently completed processing Sludge Batch 3 (SB3) at a maximum melt rate of 150 lbs/hr at 38% waste loading, resulting in a waste vitrification rate of 57 lbs/hr. Given the size of the DWPF JHM, this equates to a melt flux of 5.3 lbs/hr/ft^2, and a waste flux of 2.0 lbs/hr/ft^2. Because SB3 was well characterized through the DWPF, a SB3 surrogate was chosen and processed through the 650 mm CCIM. At an operating temperature of 1250°C, a maximum melt rate of 46 lbs/hr at 53% waste loading, resulting in a waste vitrification rate of 24 lbs/hr was achieved. Given the size of the CCIM, this equates to a melt flux of 12.8 lbs/hr/ft^2, and a waste flux of 6.8 lbs/hr/ft^2. Using melt flux to scale the CCIM for DWPF a 950 mm CCIM may achieve a melt rate of ~100 lbs/hr and a waste vitrification rate of ~50 lbs/hr. Based upon the premise of installing two 950 mm CCIMs in the DWPF, the waste vitrification rate may be increased by almost 2x that of the existing DWPF JHM.

FEASIBILITY OF INSTALLING TWO 950 mm CCIMs IN THE DWPF

The CCIM uses induction heating to maintain molten glass at high temperature. A water cooled helical coil (induction coil) is connected to an AC current supply (typically operating at frequencies from 100 KHz to 5 MHz). The oscillating magnetic field generated by the current flow through the coil induces oscillating currents in conductive materials within the coil. Those currents, in turn, generate heat in the material.

In the CCIM, the induction coil surrounds a "Cold Crucible" which is formed by metal tubes (typically copper or stainless steel). The tubes are constructed such that inductive coupling to them is minimal. Therefore the field generated by the induction coil penetrates through them to the conductive medium (hot glass) within. The crucible tubes are water cooled to maintain their temperature between 100^o C to 200^o C so that a protective layer of molten glass and/or batch material (a "Skull") forms between them and the hot melt. This skull has been estimated to be between 5 and 10 mm thick.

Because glass batch materials or cold glass are not electrically conductive, the system depends on use of another susceptor (typically a graphite or metal ring) to couple with the imposed field and provide initial heating. Once the glass is hot enough to conduct electricity the field can couple directly with it for heating to continue. The start-up susceptor is then eventually oxidized. Because the protective skull is the only material directly in contact with the molten glass, the CCIM doesn't have the temperature limitations of traditional refractory lined Joule heated melters. It can be operated at melt temperatures over 2000^{o}C. This can allow processing of high waste loading batches and difficult-to-melt compounds. The CCIM is poured through a bottom drain. In some designs this is an induction heated tube that alternately forms and melts a "glass freeze plug". In other designs the drain is a water cooled slide valve that starts and stops the pour stream. Pouring can be performed continuously or in batch mode. A schematic diagram of a CCIM as described by the CEA is shown below.

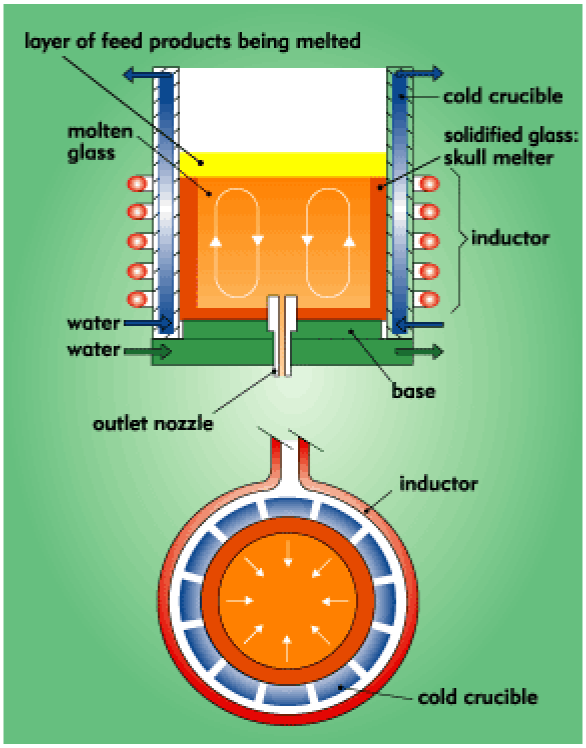

Fig. 1: Schematic diagram of a CCIM as described by the French Atomic Energy Commission

The DWPF could benefit from use of CCIM technology, especially in light of our latest projections of waste volume to be vitrified. Increased waste loading and increased throughput could result in substantial life cycle cost reduction. Given the recently demonstrated performance of a 650 mm diameter CCIM using DWPF simulant feed, it may be necessary to install two 950 mm CCIMs in the DWPF Melt Cell in order to significantly surpass the capability of the currently installed JHM. A cursory evaluation of system design requirements and modifications to the facility that may be required to support installation and operation of two 950 mm CCIMs is provided.

The following items have been identified that must be evaluated for implementation of CCIM technology:

Facility design & support capability

- Location of the two CCIMs in the Melt Cell within the currently installed DWPF Melter footprint.
- A revised canister handling method must be developed to allow for staging of an empty canister, a canister under the CCIM for filling, and removal of the canister for each CCIM, independently. Schematic provided in Figure 2.

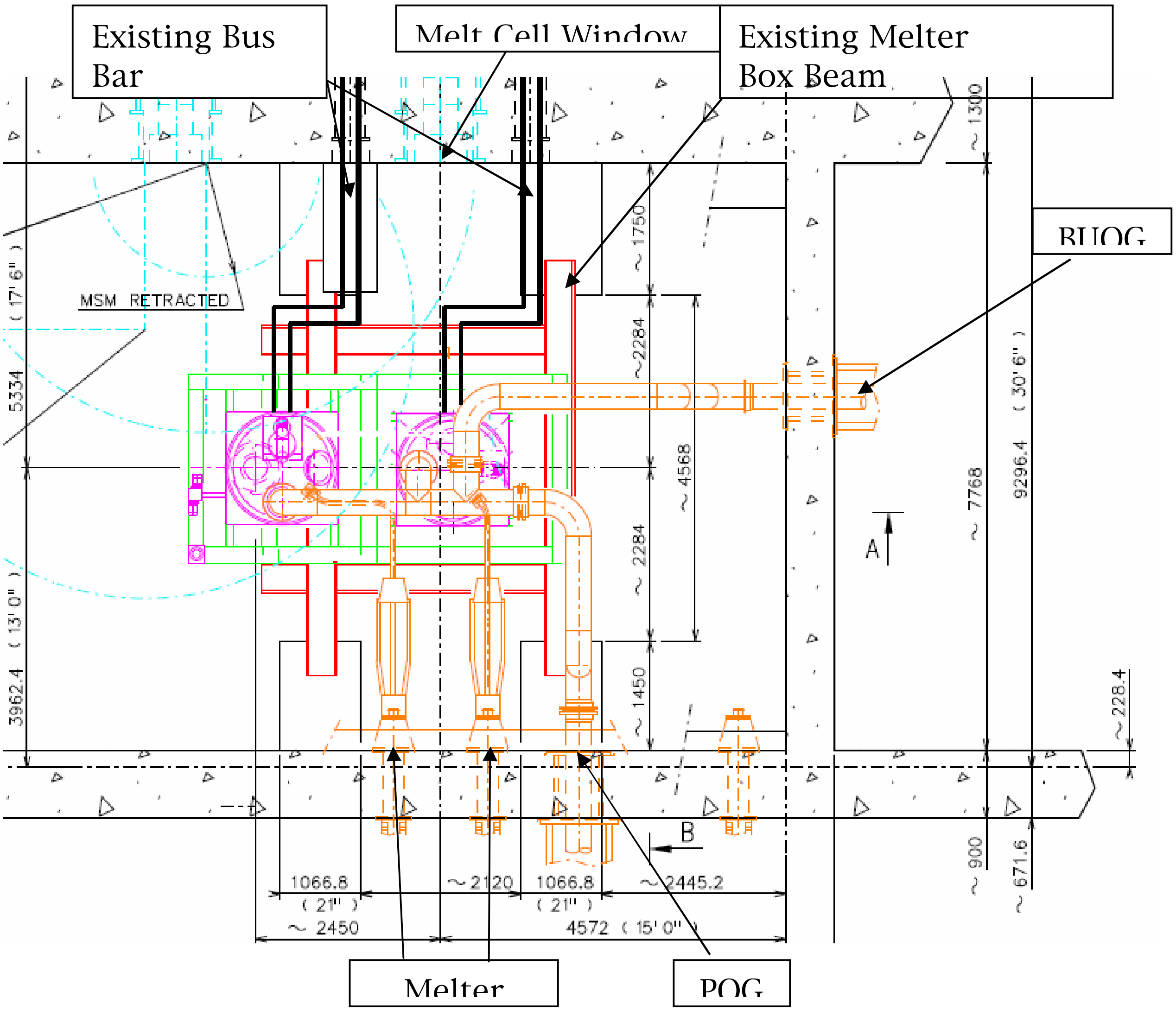

Figure 2: Proximity of CCIM locations within DWPF Melt Cell

- Increased power requirement & ability to provide it.
    - Each 950 mm CCIM requires a 600 kW power supply, so 1.2 MW must be made available. This may require increasing the capability to the Melter Power Control Area on the Second Level East Corridor of the DWPF.
- Geometry of CCIM Power Supplies
    - Given the power supply geometry for the proposed 1.3 m CCIM as standard, two power supplies of this geometry can physically fit in the current Melter Power Control Area on the Second Level East Corridor of the DWPF. However orientation of these power supplies with thru-floor penetrations for bus-bars needs further evaluation. The CCIM High Frequency Generator (HFG) overall dimensions are 3.5m x 0.6m x 2.2m (l x w x h). The Melter Power Control Area is provided in Figure 3 below.

Figure 3: Proposed Location for High Frequency Generator

- Need to locate the Impedance Adaptor Cabinet very close to the melter.
    - Bus-bars from the HFG can be fed through the Second Level floor penetrations to the First Level to the Impedance Adaptor Cabinet (IAC). The IAC needs to be located as close to the CCIM as possible to minimize electrical losses. Each feed from the IAC may be adapted to enter the melt cell through the existing melter bus-bar through-wall penetrations. AREVA has identified the need to modify the CCIM bus-bars so that they may fit through the existing through wall penetrations. The IAC approximate dimensions are 1.5m x 0.6m x 2.2m. Figure 4 shows the proposed location of the two IACs required to power the two 950 mm CCIMs. Modifications to this area are required to support installation of the two IACs.

Figure 4: Proposed location for two IACs required to power the two CCIMs.

- Need to feed RF power (water cooled leads) through shield wall and be able to remotely connect/disconnect them.
    - Existing bus-bar penetrations are appropriate for providing through-wall electrical connection to each CCIM.
    - As AREVA has identified, the dimensions of the existing DWPF penetrations are smaller that those currently used for the CCIM, so it will be necessary to adapt the design of the HF through-wall penetrations to accommodate the current DWPF configuration.
- Need to meet CCIM cooling water requirements.
    - AREVA has indicated that two cooling water loops are required for each CCIM. Cooling Loop 1 is dedicated to cooling the shell of the CCIM processing vessel. Cooling water required to be between 105°C and 120°C at 2 to 3 bars. Based upon a 1.0 MW 1.3m CCIM, the Loop 1 cooling water requirements are ~60% of the total power. Applying this ratio to the 600 kW 950 mm CCIM predicts the required cooling capacity to be about 360 kW per each of the two melters, totaling approximately 720 kW of heat to dissipate.
        - Existing Melter Cooling Water temperature is ~55° C.
    - Cooling Loop 2 is dedicated to cooling the high-frequency equipment. Based upon a 1.0 MW 1.3m CCIM, the Loop 2 cooling water requirements are ~40% of the total power. Applying this ratio to the 600 kW 950mm CCIM predicts the required cooling capacity to be about 240 kW per each of the two melters, totaling approximately 480 kW of heat to dissipate.
    - Total cooling water capacity: ~1.2MW. To achieve this amount of heat dissipation, not only will the Melter Cooling Water System have to be redesigned, but an increased capacity of the Cooling Water Tower may be required to ensure dissipation of the additional heat.
    - The water flow requirement for Loop 1 is ~250 gal/min. The water flow requirement for Loop 2 is ~350 gal/min.
        - Existing Melter Cooling Water flow capability is ~600 gal/min
    - Figure 5 shows the proposed location for the CCIM cooling water loops.

Figure 5: Proposed location for CCIM cooling water supply.

- Need to revise canister handling method.
  - To ensure 70 lbs/hr glass may be achieved for each of the two 950mm CCIMs, it is necessary to decouple operation of the two melters. In terms of canister handling, that means that a conventional turntable system, similar to what is currently installed, will not adequately support operation of both melters. A revised canister handling method must be developed to allow for staging of an empty canister, a canister under the CCIM for filling, and removal of the canister for each CCIM, independently.
- Ability of canister to withstand higher fill rate with higher temperature glass. Need to assess impact of this on ability to decontaminate canister.
  - During filling of the DWPF canister, an oxide layer forms that traps contamination on the surface of the canister. During canister decontamination, glass frit and water are used to mechanically clean the exterior surface of the canister. It may be that due to the increased temperature of the glass, the decontamination cycle may have to be modified to ensure adequate cleaning of the canister surface.
- Ability to tie-in to off-gas system and for it to handle volatiles from high temperature operation.
  - For this feasibility study, Engineering is assuming that the primary off-gas system may be aligned to both CCIMs at the same time. This also assumes that the total off-gas flow for two 950mm CCIMs is comparable to the currently installed DWPF Joule Heated melter. Controls and interfacing the existing off-gas system to the CCIMs would have to be developed.
- Ability to tie-in to feed system.
  - Installing two CCIMs would require dedicating each feed loop to one CCIM. The slurry feed rate capability with the currently designed system is ~0.25 gpm to 0.90 gpm. Given typical calcined solids concentrations of ~42 wt. %, a slurry feed rate of 0.25 gpm gives ~70 lbs/hr of glass, the assumed maximum glass throughput for a 950mm CCIM. This indicates that the feed delivery system may need to be redesigned to operate more within the range of the CCIMs glass production

capability. Controls and interfacing the existing feed system to the CCIMs would have to be developed.

- Ability of other DWPF systems to support dual CCIM operations. i.e. Feed preparation, canister decontamination, and canister welding.
  - For this feasibility study, it is assumed that the glass production rate is ~70 lbs/hr. It is also assumed that the waste loading is ~50 wt. %. Operating two CCIMs in parallel results in a glass production rate of ~140 lbs/hr and a waste throughput of 70 lbs/hr. DWPF has demonstrated ~150 lbs/hr at 38wt. % waste loading resulting in a waste throughput of ~57 lbs/hr. Based upon this comparison, feed preparation, canister decontamination, and canister welding should not be a bottleneck to operations.
- Remote Maintenance
  - In order to maintain each of the two CCIMs, it is necessary to develop additional remote service equipment in addition to the currently installed MSM and TRM.
- Level Detection Capability
  - Currently, an infrared level detection system is used to determine glass fill height within each canister. To support dual CCIM operations, two IR level detection systems must be available. Controls and interfacing systems for a second IR level detection system would have to be developed.

CONCLUSION

From the cursory evaluation performed, it appears technically feasible to position two CCIMs in the Melt Cell of the DWPF within the existing footprint of the current melter. Interfaces with support systems and controls including Melter Feed, Power, Melter Cooling Water, Melter Off-gas, and Canister Operations must be designed to support dual CCIM operations.