Status Update - Installation and Operation of GeoMelt® ICV™ Process in the NNL's Central Laboratory on the Sellafield Site –16410

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ABSTRACT

Thermal treatment of nuclear waste in the UK has seen much renewed interest recently, owing to the advantages that can be gained in terms of reduced waste volumes, compatibility with reactive metals and organics and its ability to treat mixed generic wastes.

Vitrification is a treatment option which destroys organics and some hazardous inorganics such as asbestos, reduces wasteform volume, and produces a robust leach resistant wasteform. Kurion's GeoMelt®[1] In-Container Vitrification (ICV)™[2] is a vitrification process where the treatment vessel can serve as an interim-storage, transport, and final long-term storage vessel - thus negating the need to pour glass into a separate container, effectively leading to a much simpler system than traditional waste melters.

The UK's National Nuclear Laboratory (NNL) and Kurion have entered into a joint project to deploy an active waste ICV™ plant based on Kurion's GeoMelt® technology, at NNL's flagship Central Laboratory on the Sellafield site. NNL is the UK's national laboratory for civil nuclear science and technology, providing advice to government, protecting key skills, supporting industry and delivering national nuclear programs. NNL is bringing the Kurion GeoMelt® process alongside its existing capabilities in thermal waste treatment. Kurion provides technology solutions to minimize and stabilize nuclear and hazardous waste through its families of technologies: access, separation and stabilization processes.

The GeoMelt® plant being installed at the NNL's Central Laboratory creates a platform to evaluate the vitrification technology for the variety of wastes from the NDA estate and creates a treatment path for problematic waste streams that currently have no disposition pathway. With the diverse facilities under NNL management coupled with the ability to import wastes from within the UK and Europe, this arrangement with Kurion provides waste owners with treatment disposition pathways for problematic wastes.

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[1] GeoMelt® is a registered trademark of Geosafe Corporation.
[2] In-Container Vitrification (ICV)™ is a trademark of Kurion, Inc.

The Kurion / NNL team completed non-radioactive commissioning of a GeoMelt® ICV™ treatment system in 2015. Commissioning consisted of performing two tests at NNL's Workington Laboratory. Commissioning Test 1 involved vitrification of 367 kg of glass frit over the course of approximately 18 hours. Commissioning Test 2 consisted of processing 470 kg of soil and additives in approximately 27 hours. The soil processed in the second test was non-radioactive soil from Sellafield and was used as an analog for radioactive soil to be processed during radioactive commissioning at the Central Laboratory at Sellafield. All commissioning test goals were easily achieved and all subsystems operated as designed. Radioactive commissioning will be carried out in early 2016.

INTRODUCTION

Thermal treatment of nuclear waste is undergoing renewed consideration in the UK and elsewhere, in part owing to the recognition of limitations of other treatment approaches, such as grout encapsulation. Vitrification has been recognized internationally as the established treatment method for high level nuclear waste for many years, but only until recently has it been considered as an option for lower level radioactive waste treatment in the UK. The UK Nuclear Decommissioning Authority (NDA) is currently evaluating thermal treatment for Low Level Waste (LLW) and Intermediate Level Waste (ILW). A symposium specifically focusing on thermal treatment of nuclear waste was held in the UK for the first time in 2013, and recognized UK academia are allocating resources for the study and promotion of thermal treatment technologies for disposition of LLW and ILW [1].
The UK's National Nuclear Laboratory (NNL) and Kurion, Inc. are jointly deploying a GeoMelt® In-Container Vitrification (ICV™) system at NNL's Central Laboratory at Sellafield, Cumbia, UK. Sellafield is the UK's primary nuclear decommissioning, fuel reprocessing, and research site owned by the NDA and managed by Sellafield, Ltd. The Central Laboratory at Sellafield is NNL's primary nuclear research and development facility.

The first step of deployment consisted of non-radioactive commissioning of the GeoMelt® ICV™ system at NNL's Workington Laboratory. This commissioning was completed in October 2015 and the GeoMelt® ICV™ system has been relocated to the Central Laboratory at Sellafield for radioactive commissioning. This paper discusses non-radioactive commissioning at the Workington Laboratory.

TECHNOLOGY DESCRIPTION

Technology Overview

Although relatively unknown in the UK until recently, Kurion's GeoMelt® vitrification technology has been used for treatment of low level and mixed radioactive wastes in the US for over two decades and in Australia and Japan for more than a decade. Over 26,000 metric tons of radioactive and hazardous wastes have been treated with the GeoMelt® process, with half of this being radioactive materials.

GeoMelt® incorporates a range of patented and proprietary vitrification technologies configured in a variety of ways depending on the waste. The process transforms hazardous chemical and radioactive waste into a chemically stable wasteform with chemical and mechanical characteristics vastly superior grouted wasteforms. Hazardous organic chemicals organics are destroyed by pyrolysis and heavy metals and radionuclides are safely oxidized and immobilized within the molecular structure of the glass.

GeoMelt® ICV™ is a batch process that is carried out in (single-use) refractory-lined steel containers. The waste is blended with glass-formers and melted using Joule (resistive) heating generated by electrical current supplied by graphite electrodes positioned in the waste. The Joule heat is initially generated in a consumable array of conductive material connecting the electrodes which elevates the temperature of the waste to the point where it becomes molten. Once molten, the waste is conductive and the electrical current is transferred throughout the waste material as the melting process propagates. Since glass is much denser than most wastes, significant volume reduction occurs during the melting process. As the melt progresses additional waste is fed into the ICV™ container in order to fill it.

ICV™ containers range from small (i.e., 206-liter drums) [2] to fairly large (i.e., purpose-built containers that hold over 44,000 kg of glass) [3]. Figure 1 depicts ICV™ containers of various sizes that have been used in the past for radioactive waste treatment. The container serves as the transport and disposal container, eliminating the usual (but complex) step typical of other joule-heating vitrification methods of transferring molten glass into a separate transport and disposal containers. Because pouring of molten glass is not required for the GeoMelt® ICV™ technology, a wider range of waste chemistries may be processed at higher melt temperatures with less additives needed to control rheology, allowing for higher waste loadings and a less complex process plant. All of which improves the economics of the process.

Figure 1. Size Ranges of GeoMelt® ICV™ Containers

GeoMelt® ICV™ System Description

The GeoMelt® ICV™ system used for the NNL commissioning consists of the following subsystems divided into zones as discussed below. Figure 2 shows the system components installed at NNL's Workington Laboratory.

Zone 1 includes a 150 kW Scott-T transformer that converts 3-phase input power to 2 independent phases that are directed to the electrode pairs embedded in the melt. Also included in Zone 1 is the ICV™ container which consists of a 200 liter-capacity cast refractory box inside a larger steel box. Additional liner material provides thermal insulation and increased electrical isolation between the melt and the steel. The ICV™ container is capped by an off-gas containment hood that supports four vertical electrode feeders. Off-gases generated by melt operations are vented though an outlet in the hood to the off-gas treatment system. The hood also supports the waste feed system which consists of a dual-valve airlock and a feed hopper. A high-temperature infrared (IR) camera that continuously displays and records real-time imagery of the melt surface is also mounted to a viewing port into the front side of the hood.

Zone 2 consists of the first stage of the off-gas treatment system, the sintered metal filter (SMF). The SMF captures 99.5 % of particulate equal to or greater than 1 micron. The filter is designed for high temperature air flow and has an integrated back-pulsing system that dislodges particulates captured on the filter assemblies. When back pulsed, captured particulate are routed to a particulate bagging system where they are collected in a plastic bag which is then sealed. This particulate can then be recycled into the melter during a subsequent melt. Although not normally used, a bypass line incorporating a high temperature High Efficiency Particulate Air (HEPA) filter is also available for use instead of the SMF.

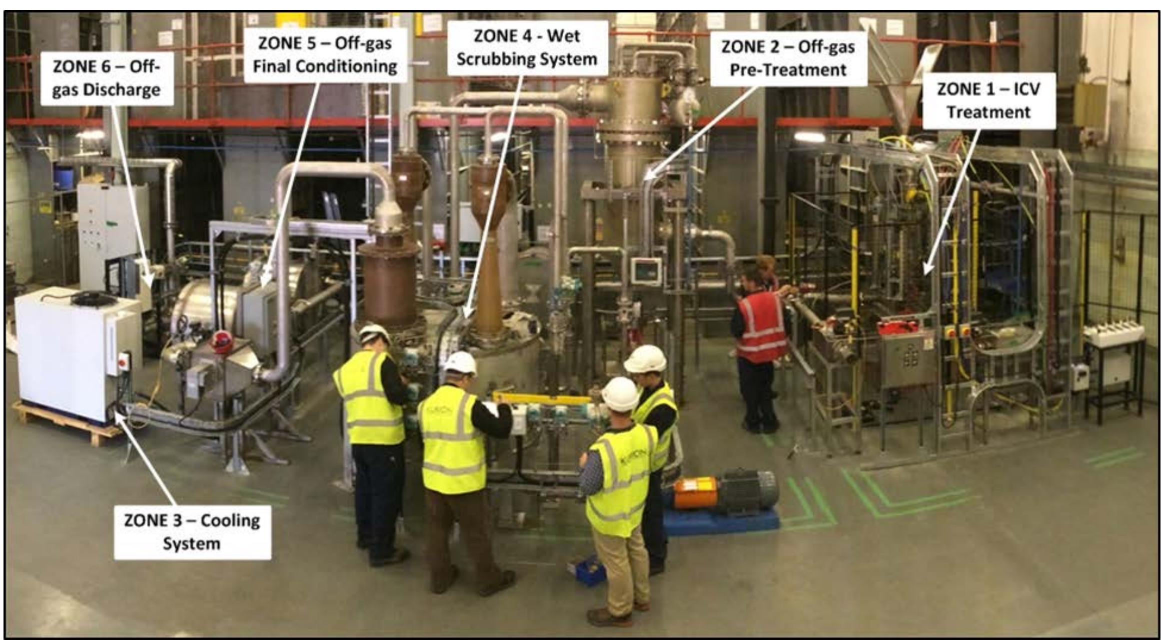


Figure 2. GeoMelt® ICV™ System at NNL Workington Commissioning.

Zone 3 is a secondary liquid cooling system. Water from the scrubbing system passes through the primary side of a plate heat exchanger, transferring heat across the plates to the secondary side and into a cooling liquid that is chilled by a dedicated chiller unit.

Zone 4 is directly downstream from the SMF where the off-gas enters a wet scrubbing system consisting of two venturi scrubbers connected in series, followed by a mist eliminator. The venturi scrubbers cool the off-gas, remove additional particulate, and neutralize corrosive (acid) gasses that may have passed through the first stage filtration. The mist eliminator removes entrained water droplets before the off-gas leaves the scrubbing system to the final conditioning stage.

In Zone 5 the off-gas passes through an electrical heater that raises the gas temperature (nominally by 10°C) to ensure any entrained water is kept in a vapor phase for the final off-gas treatment. After heating, the off-gas enters a final HEPA filter to remove remaining particulate, and then enters the primary off-gas fan for discharge to the stack. A backup HEPA circuit filter and backup off-gas blower are available if needed.

DESCRIPTION OF COMMISSIONING ACTIVITIES

Kurion's GeoMelt® ICV™ system being installed in the U.K. had been previously used for non-radioactive testing in the U.S. and U.K. since 2009. In 2015 the system was significantly upgraded for nuclear operations and use on the Sellafield site. Upgrades include new off-gas piping, pumps, instrumentation, scrub tank and chiller, and also a larger melt power supply transformer. These upgrades were carried out to ensure compatibility with NNL's Central Laboratory ventilation, for laboratory-specific permit compliance, and also to be able to process larger amounts of waste. This significant nuclearization upgrade necessitated a comprehensive re-commissioning program. In order to streamline this commissioning process, non-radioactive commissioning was performed at NNL's Workington Laboratory rig hall, with radioactive commissioning to be performed in early 2016 at NNL's Central Laboratory at Sellafield.

Two commissioning tests were performed with this system at the Workington Laboratory. The first commissioning test was carried out to confirm proper system operation. The second test was performed to demonstrate the ability to effectively treat Sellafield soil with GeoMelt® ICV™. Contaminated soil can be mixed with other ILW to provide glass formers for GeoMelt® ICV™ and the second non-radioactive commissioning test was performed as a preliminary demonstration of this concept.

Commissioning Test 1

Commissioning Test 1 was successfully completed on November 4, 2015. The test involved processing glass frit obtained from NNL's Vitrification Test Rig (VTR) project. An initial batch of 229 kg followed by 138 kg of feed material were processed. The overall test duration was 18 hours, 48 minutes. Figure 3 shows the melt surface during feed processing as viewed through the IR camera. Figure 4 shows the quantity of material processed over the course of the test. The overall processing rate was 19.5 kg/hr. The processing efficiency was 1.73 kWh/kg.

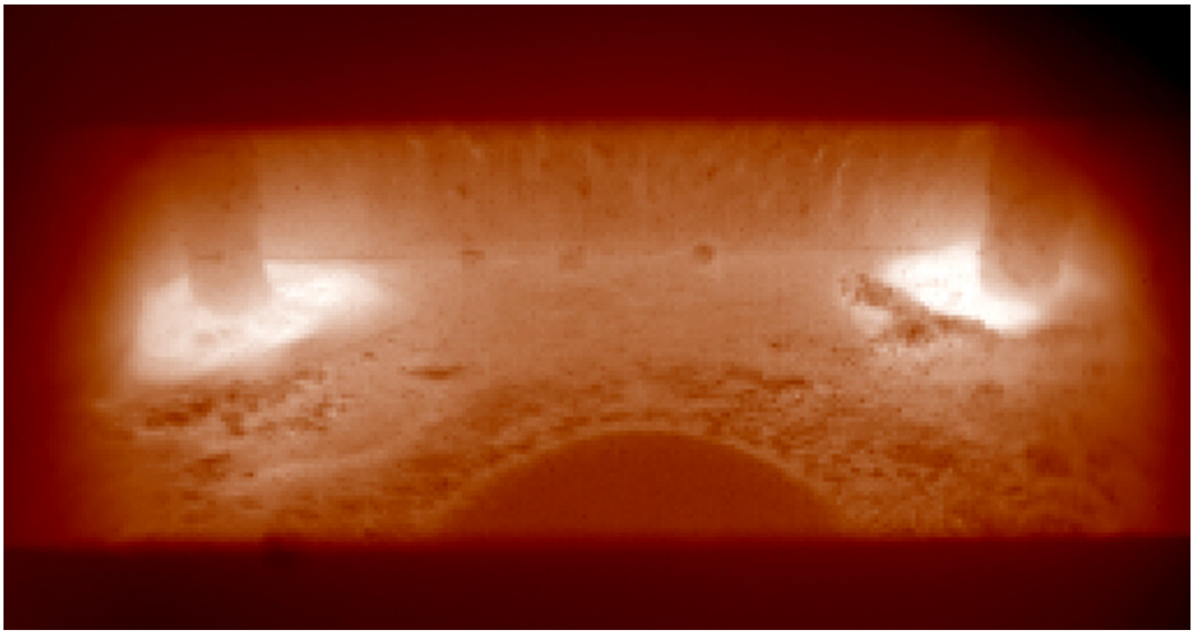


Figure 3. Commissioning Test 1 Melt Surface

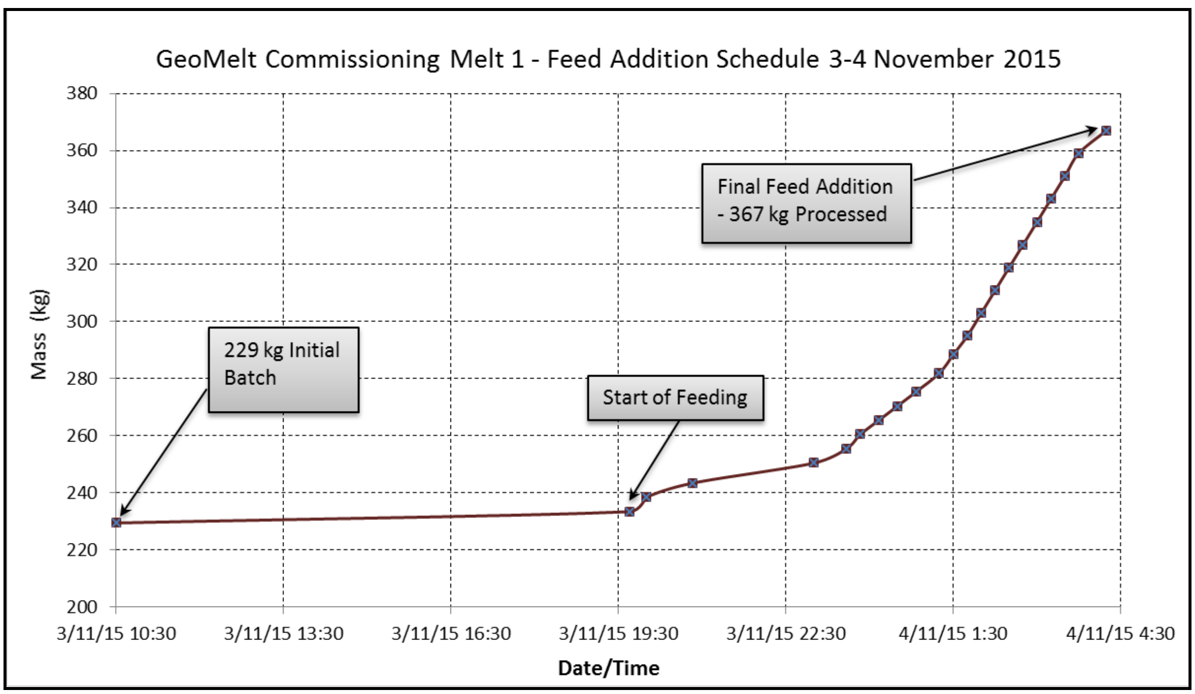


Figure 4. Material Processed Over the Course of Commissioning Test 1

The melt was instrumented with three Type K thermocouples in alumina sheathes that penetrate the cast refractory wall at various depths. The melt was initiated at the top of the frit batch (approximately 50 mm from the refractory rim) and progressed down as it developed. The vertical electrodes move downward through feeders equipped with remote-controlled grippers that allow each electrode to be controlled independently. In addition to monitoring the view inside the ICV™ container with the IR camera, melt progress is tracked by operators by visual observation of the electrode position and by the response of the thermocouples embedded in the melt. Figure 5 shows the thermocouple response to melt conditions during Commissioning Test 1. Each thermocouple rises in temperature as the material around it rises in temperature and levels off (more or less) as the surrounding material becomes molten. The frit melting temperature is 1150 °C. Melt temperature is dependent primarily on waste chemistry, but also on electrical power input which is varied in response to melt surface conditions. The upper thermocouple (TI-101) is seen to decrease substantially approximately halfway through the test. This temperature decrease coincides with the volume reduction of the initial batch which exposed the thermocouple to the ICV™ container plenum. As additional feed material was added to the melt container the level of the melt moved upwards eventually submersing the upper thermocouple within the melt.

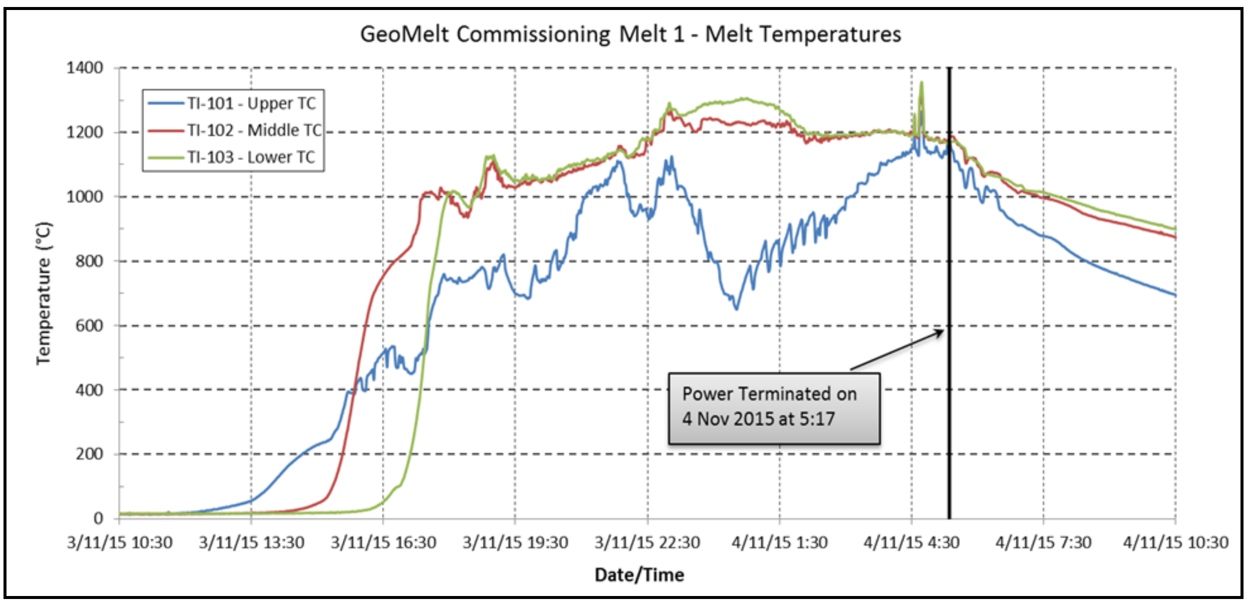


Figure 5. Commissioning Test 1 Melt Temperatures

Commissioning Test 2

Commissioning Test 2 was successfully completed on November 11, 2015. The test involved processing non-radioactive soil blended with additives. The soil was obtained from a quarry adjacent to Sellafield, so as to have analogous geochemical characteristics of contaminated soil at Sellafield. This soil was high in silica (83 wt%) so it was blended with additives to lower the melting temperature from an approximately 1700 °C to 1200 °C. Note that while 1700 °C is a temperature well within the range of GeoMelt® ICV™ capabilities, the soil was fluxed in order to demonstrate a temperature range optimized to mitigate volatility of semi-volatile radionuclides (e.g., Cs-137); a similar temperature range will be used for the radioactive soil commissioning at the Central Laboratory at Sellafield. The soil was blended with boron, sodium, and calcium as oxides and carbonates. An initial batch of 203 kg followed by 267 kg of feed material were processed. The overall test duration was 27 hours. Figure 6 depicts the mass of material processed over the course of the test. The overall processing rate was 17.4 kg/hr. The processing efficiency was 1.88 kWh/kg.

Melt temperatures are displayed in Figure 7. As in Test 1, it can be seen that the upper thermocouple only registered the target melt temperature of 1200 °C after well after the initial batch had been processed and feeding had been initiated as to fill the cast refractory to the level of thermocouple TI-101.

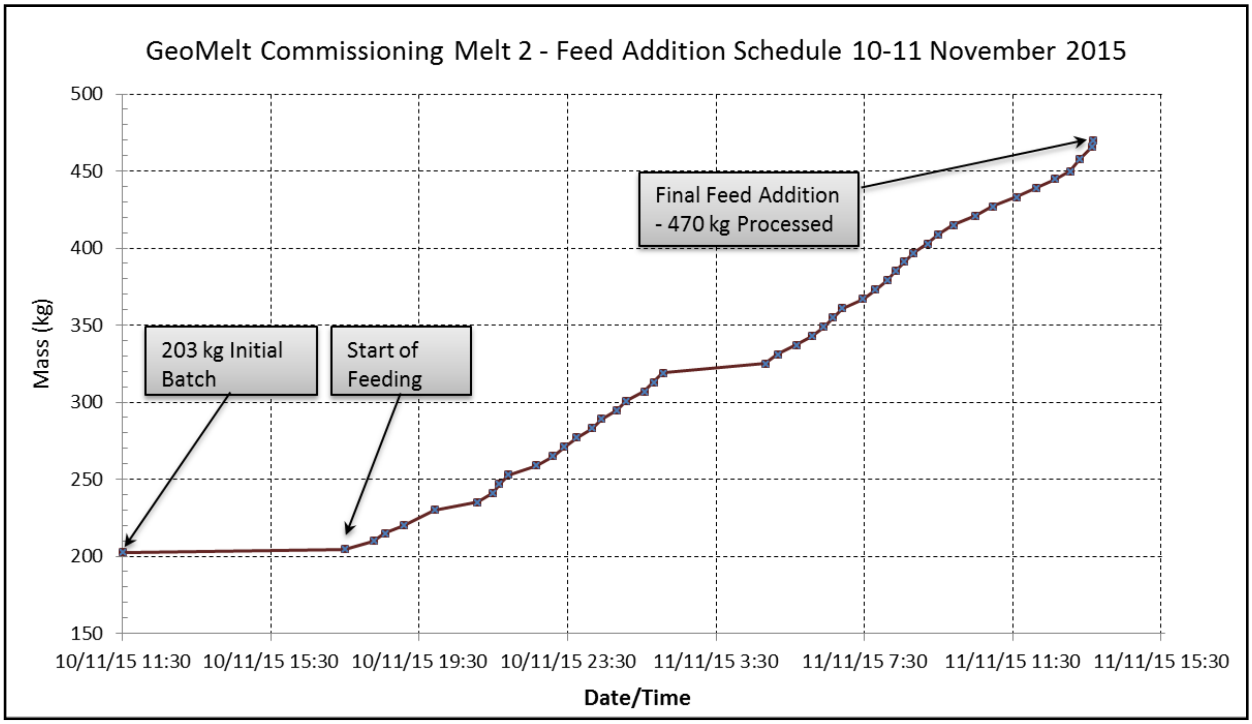


Figure 6. Material Processed Over the Course of Commissioning Test 2

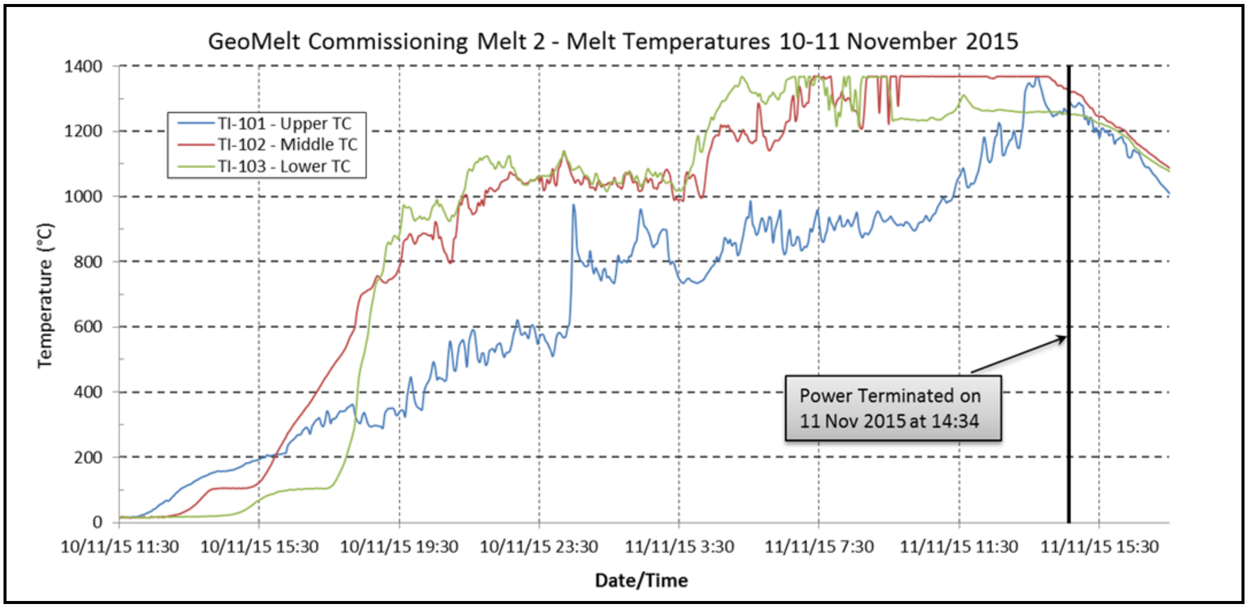
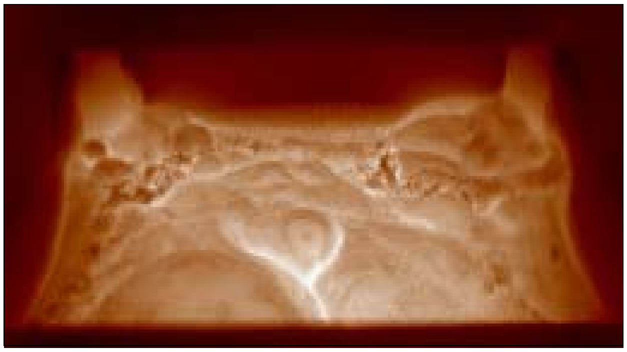
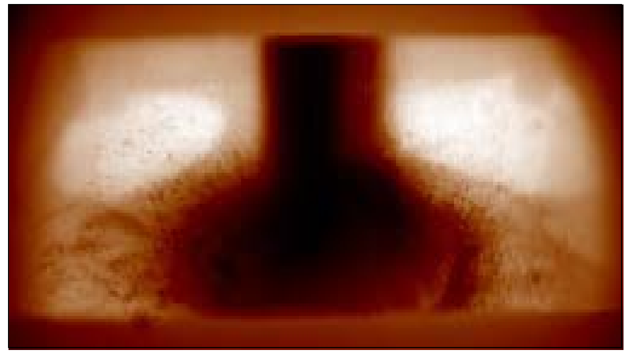


Figure 7. Commissioning Test 2 Melt Temperatures

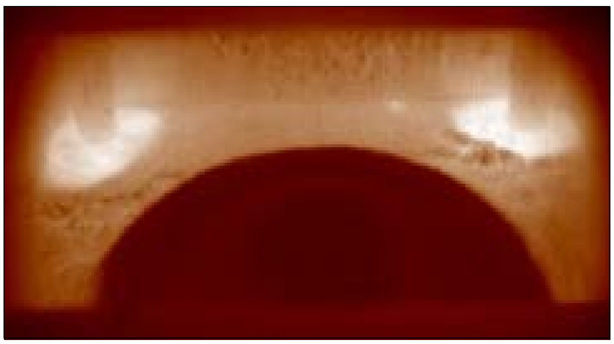
Figure 8 shows key stages of Commissioning Melt 2 as captured by the IR camera. The back two electrodes (vertical cylindrical shapes) are visible in several of the images. The melt surface after processing the initial batch of soil and additives can be seen in the first image. Once the surface is molten, additional material is fed though the airlock feed system. Successive feed piles are processed (as shown on Figure 6) until the container is filled.



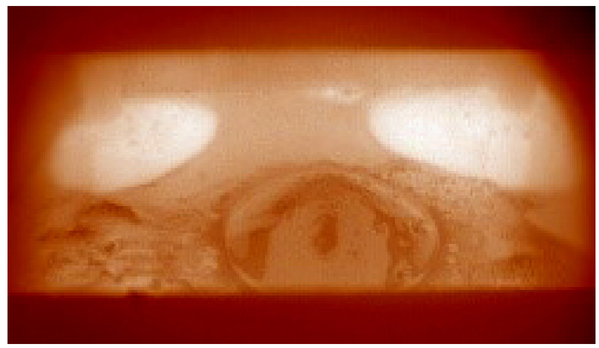
Molten glass surface ready for feed addition.



Feed material being added to the melter.



Feed pile being being incorporated into the molten glass.



Final feeding completed.

Figure 8. IR Camera Sequence during Commissioning Melt 2

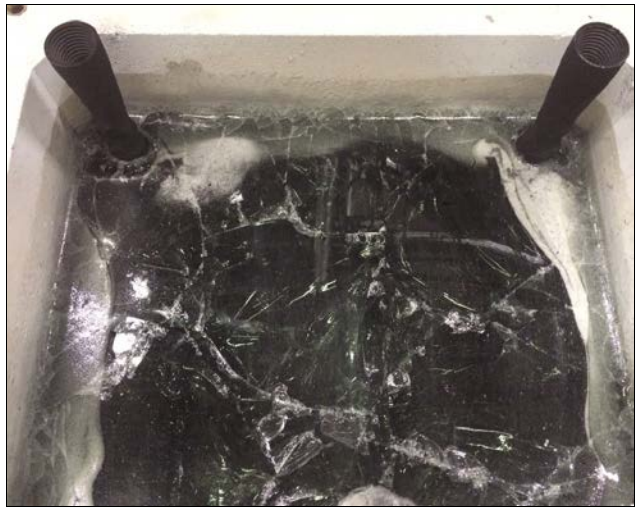
DISCUSSION

Both commissioning tests were carried out without operational difficulty or incident. Key processing data for Test 1 and 2 are provided in Table 1. After sufficient time for cooling after each test, the cast refractory lining and glass was removed from the ICV™ container for inspection and documentation. Figures 9 and 10 show these activities for Commissioning Test 1 and 2, respectively. All material in both tests was fully processed and the glass product was homogenous. The glass in Test 2 did contain frozen bubbles which account for the whitish surface appearance seen in Figure 10. Such bubbles can form as residual gas is evolved from the melt upon cooling and have no adverse effect on glass product quality. All objectives were satisfied with these commissioning tests. All commissioning test goals were easily achieved and all subsystems operated as designed.

Table 1. Summary of Operational Performance Metrics

Test Metric	Test Melt 1 Glass Frit	Test Melt 2 Sellafield Soil
Test Period	3 Nov 2015 @ 10:29 a.m. to 4 Nov 2015 @ 5:17 a.m.	10 Nov 2015 @ 11:30 a.m. to 11 Nov 2015 @ 14:34 a.m.
Test Duration	18 hrs., 48 min	27 hrs., 4 min
Total Mass Processed (kg)	367	470
Total Power Usage (kWh)	636	882
Unit Energy Input (kWh/kg)	1.73	1.88
Product Waste Loading (wt %)	N/A	68.53
Feed Addition Rate (kg/hr)	16.2	13.2
Overall Melt Processing Rate (kg/hr.)	19.5	17.4
Final Glass volume (L)	147	151
Final Glass Mass (kg)	367	378

Removing finished product out of ICV™ Container for inspection.



View of the glass surface showing homogenous vitrified product

Figure 9. Commissioning Test 1 Glass Product

Inner refractory vessel being lifted directly out of the outer steel ICV™ container.

Surface of the solidified glass product in ICV™ container.

Figure 10. Commissioning Test 2 Glass Product

RADIOACTIVE COMMISSIONING

The GeoMelt® ICV™ system currently is undergoing installation at the NNL Central Laboratory at Sellafield. A view of Central Laboratory B-170 Rig Hall, where the system will be commissioned is shown in Figure 11. Commissioning with radioactive waste is planned for early 2016. Commissioning at Sellafield will consist of a preliminary test using glass frit (identical to the first non-radioactive commissioning test at Workington) followed by a radioactive test using radioactive contaminated soils.

Figure 11. NNL Central Laboratory B-170 Rig Hall

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2. P.S. LOWERY, M. HASS, Innovative Vitrification Method Demonstrated for the Treatment of Pyrophoric Uranium Chips and Oil, WM'00 Conference, Tucson, AZ, March (2000).

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