

Cold crucible deployment in La Hague facility: the feedback from the first four years of operation - 15119

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ABSTRACT

In April 2010, a Cold Crucible Induction Melter (CCIM) started hot operation for the first time ever in an existing very high active facility (R7) at La Hague. This was the culmination of more than two decades of R&D involving progressive process and technological development. The industrial deployment included extensive cleaning of the hot cell, removal of the previous melter, exchange of several mechanical and process components in the cell, and implementation of the various additional utilities and components necessary for operation of the new CCIM. The design and implementation phases for this deployment were described in a previous paper at WM [1].

The CCIM has now been operated for more than four years, essentially processing active effluents from D&D operations and high-level liquid waste from reprocessed U-Mo-Sn-Al spent fuel.

During this period, many data have been collected to confirm the process parameters that were defined during the qualification of this innovating process. Even if some difficulties occurred, the experience of the operating teams with the support of engineering and R&D allow managing them.

This paper presents the start-up methodology and history of the cold crucible deployment in La Hague facility with the feedback from the first years of operation. The production records with the different liquid solutions treated in the process are itemized. The lessons learned during the first four years of operation of the CCIM are presented with the difficulties encountered and the solutions implemented, emphasizing the benefits of a close integration between R&D, engineering, and operation teams.

INTRODUCTION

Vitrification of high-level liquid waste is the internationally recognized standard to minimize the environmental impact resulting from radioactive waste disposal and the volume of conditioned waste. In France, high-level liquid waste arising from nuclear fuel reprocessing has been successfully vitrified for more than 30 years with three major objectives: durable containment of the long-lived fission products, minimization of the final waste volume and operational performance achieved in vitrification plants.

The CEA (French Alternative Energies and Atomic Energy Commission) and AREVA have acquired a unique experience in the field of high-level waste vitrification through continuous efforts to improve the technology (from hot to cold crucible melter) and the associated matrix formulations, with constant emphasis on quality and volume reduction, leading to the design and qualification of the Cold Crucible Induction Melter (CCIM) technology.

As a result, AREVA has replaced one existing Induction Heated Metal Melter (IHMM) in a production line in the R7 facility at La Hague plant by a cold crucible induction melter. Among others, this technology has three main advantages: vitrification of a broad spectrum of waste because of the upper reachable melt temperatures, increase of glass production capacity, and increase of melter lifetime because of the lower wall temperature (formation of a solid glass layer).

The CCIM has started hot operation in April 2010 for the first time ever in a harsh environment at the La Hague R7 vitrification facility. The CCIM has now been in commercial operation for more than four years, processing active effluents from D&D operations and high-level liquid waste from

reprocessed U-Mo-Sn-Al spent fuel. The cold crucible deployment in La Hague facility was the culmination of several years of R&D led by the Joint Vitrification Laboratory (L.C.V), a common research laboratory between CEA and AREVA in charge of qualifying new processes and matrices for waste containment.

This paper presents the start-up methodology and history of the cold crucible deployment in La Hague facility with the feedback from the first years of operation. The production records with the different liquid solutions treated in the process are updated. The lessons learned during the first four years of operation of the CCIM are presented with the difficulties encountered and the solutions implemented, emphasizing the benefits of a close integration between R&D, engineering, and operation teams.

CCIM VITRIFICATION PROCESS OPERATED IN THE R7 FACILITY

Industrial French Vitrification Design

In France, highly active liquid wastes are vitrified into a two-step vitrification process, shown schematically in Figure 1. In the two-step process, the feed solution coming from reprocessing operation is fed to a rotary calciner which performs the evaporating, drying and calcining functions. Aluminum nitrate is added prior to calcination to avoid sticking issue in the calciner (melting of NaNO_3). Sugar is also added to the feed prior to calcination to reduce some of the nitrates and to limit ruthenium volatility. At the outlet of the calciner, the calcine falls directly into the melter along with the glass frit which is fed separately. The off-gas treatment unit recycles particulate material and purifies the gas streams, before stack release.

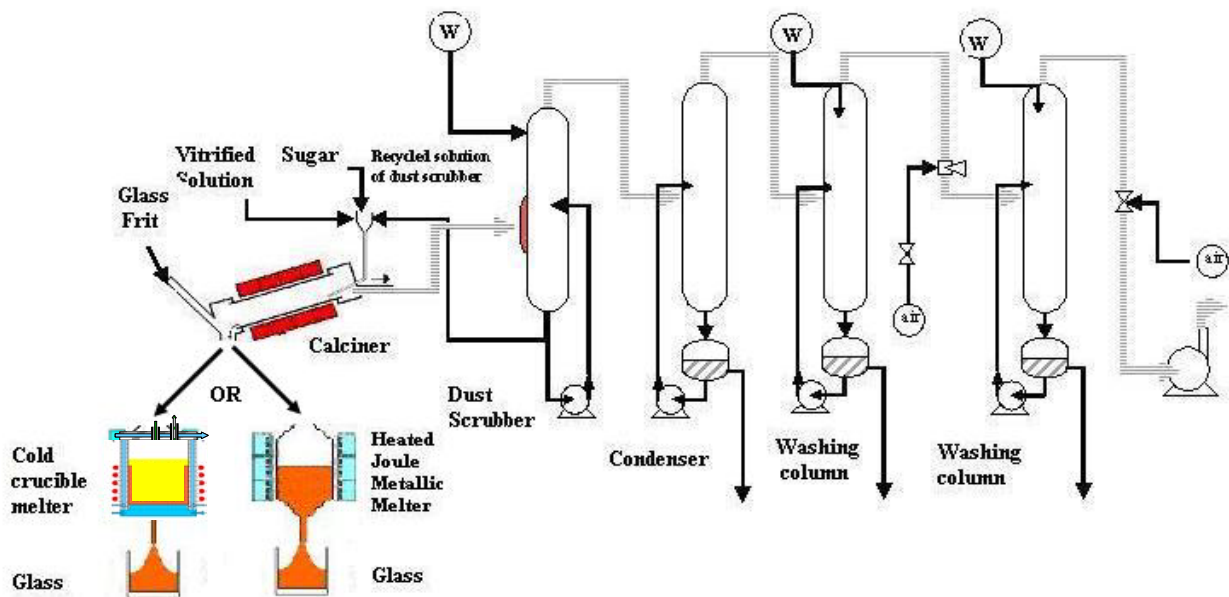


Fig. 1. Two-step vitrification process.

The calciner includes:

- a resistance furnace with four independent heating zones separated by interzone segments,
- a rotating tube,
- an upper end-fitting ensuring leak-tightness at the rotating upper end, with connections for exhausting the off-gas and for supplying the liquid feeds (vitrification feed solution, sugar and recycled solution),
- a lower end-fitting ensuring leak-tightness at the rotating lower end and guiding the calcine into the melter.

The calciner is controlled by assigning heating temperature setpoints to the electrical resistors. The calcining performance is observed by monitoring the heating power variations in each zone.

The off-gas treatment system is composed of a hot wet scrubber with weir plates, a water and nitric acid vapor condenser, an absorption column, a washing column, a ruthenium filter, and three HEPA filters. The most active gas washing solutions are recycled from the wet scrubber to the calciner. The other solutions are concentrated in an evaporator before recycling into the vitrification plant. Off-gas treatment must be capable of ensuring a satisfactory decontamination factor in the gas exhausted from the calcining and glass production operations. Liquid samples can be taken from each of the four process devices to estimate the quantity of volatilized or entrained species. Each device is also supplied with level, temperature, and pressure measurements.

Direct Induction Vitrification Principles and Advantages

The direct induction process is characterized by currents directly induced inside the molten glass by a coil (Figure 2). These electromagnetic currents heat the glass inside the melter by the Joule effect. The segmented structure of the crucible enables penetration of electromagnetic field into its volume. Absorption of electromagnetic radiation allows the glass to be heated directly without heating the crucible.

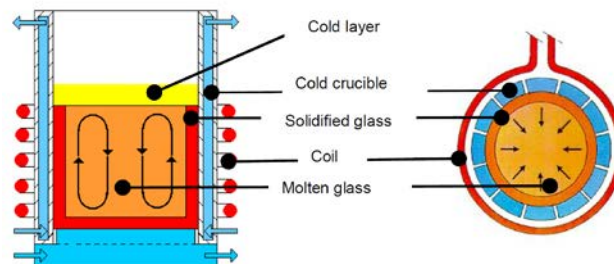


Fig. 2. Direct induction melting principle

The CCIM technology presents a number of major advantages.

First, cooling of the crucible forms a solidified layer of glass which coats the surface of the crucible in contact with the glass. This skull layer protects the crucible from the corrosive melt. The cooling of the crucible protects from corrosive vapours. Second, the direct induction heating method allows the temperature to be increased (beyond 1300°C for some new matrix formulations still being tested) making it possible to obtain new waste containment matrices which would have been impossible to produce with the hot metallic melter.

This technology can be used to vitrify many varied types of chemical waste. By allowing higher waste loading it also minimizes the volume of packaged waste. Furthermore, the presence of the cold layer minimizes the impact of the composition of the waste on the lifetime of the crucible.

Finally, when integrated into the two-step vitrification process (calcination and vitrification), as is the case in the R7 facility at La Hague, the CCIM technology allows the industrial vitrification throughput to be significantly increased. The higher temperature allows a faster calcine digestion by the glass, and consequently allows continuous feeding (no soaking period before pouring).

CCIM Design Principles

The CCIM is composed of the following elements (Figure 3):

- The metallic crucible shell, which is a segmented structure, transparent to the electromagnetic field. The cooled sectors are separated by electrical insulators.
- The crucible bottom (slab), which includes the pouring valve. A cooled duct links the crucible to the container.

- The crucible is topped by a dome which supports a mechanical stirrer.
- Glass level and temperature are continuously measured by specific sensors.
- Bubblers are positioned on the crucible slab.

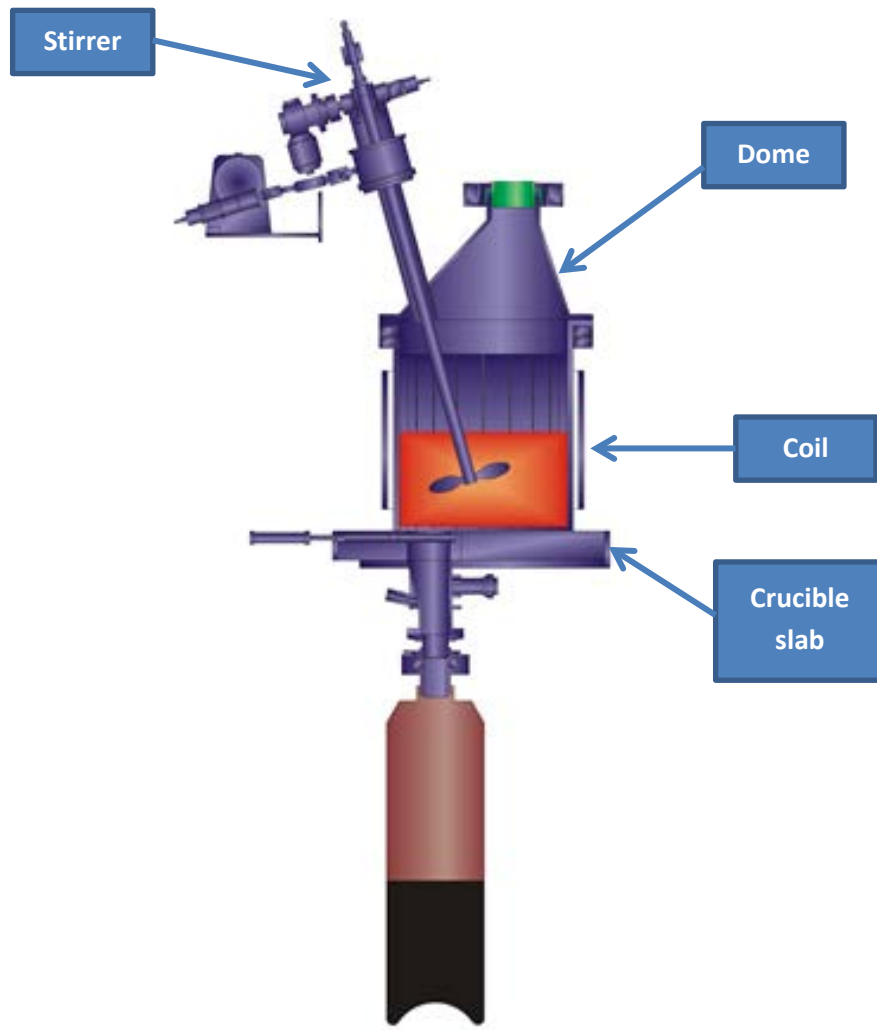


Fig. 3. Schematic drawing of a CCIM.

The crucible power supply comprises:

- A high-frequency generator with an output of around 400-600 kW.
- A high-frequency power line.
- A copper coil surrounding the crucible.

CCIM Deployment at La Hague

In April 2010, a CCIM has started hot operation for the first time ever in an existing very high active facility (R7) at La Hague. This was the culmination of more than two decades of R&D involving progressive process and technological development. The design and implementation phases for the industrial deployment were described in a previous paper at WM [1]. The main stages are detailed below.

1981 The first R&D CCIM prototype was put into service (350 mm in diameter).

- 1983 The feasibility of vitrification by electromagnetism was demonstrated. The reliability and endurance of the process were demonstrated by 800 hours of remelting inactive glass.
- 1985 **Industrialization phase 1.** A larger R&D CCIM was built (550 mm in diameter).
- 1987 The continuous two-step vitrification process of R7T7 glass was demonstrated with a reduced capacity mock-up in 175 hours of inactive melting.
- 1992 AREVA NC decided to study the implementation of the cold crucible.
- 1997 A 650 mm diameter R&D CCIM was built and tested (calcination-vitrification operation) with an industrial-range capacity for almost 3,000 hours (inactive tests).
- 2000 **Industrialization phase 2.** A specific CCIM prototype was designed and built for the specific purpose of the vitrification of highly corrosive UMo fission product solutions resulting from the recycling of legacy GCR fuels.
- 2004 AREVA NC decided to implement a CCIM in R7.
- 2005 Engineering (E&P) started the preliminary design phase of the R7 CCIM.
- 2006 **Industrialization phase 3.** A “nuclearized” R&D CCIM prototype was built, adapted to the La Hague vitrification process and environment. This CCIM was designed to vitrify a large variety of waste. It was used in Marcoule to qualify the process and glass quality. More than 6,000 hours of testing have been conducted on this platform.
Engineering (E&P) started the Detailed design phase of the R7 CCIM.
- 2007 Construction in AREVA’s Beaumont testing and development laboratory (HRB) of a full-scale test platform identical in every way to the radioactive cell environment of R7 facility. This platform was used to carry out tests outside the nuclear zone and train personnel in 2008 and 2009.
- 2008 **Industrialization phase 4.** A fully nuclearized industrial CCIM was built to be implemented in the R7 facility. This one was used to qualify the equipment in the HRB. Start of manufacturing and installation of the industrial CCIM in R7 facility.
- 2009 Start of commissioning and inactive tests of the CCIM implemented in the R7 vitrification facility (5 “inactive” canisters).
- 2010 First active operation of the CCIM implemented in the R7 vitrification facility
Five D&D effluents vitrification campaigns (decontamination effluents from the La Hague UP2-400 facility D&D operations) conducted from 2010 to 2012.
- 2013 First industrial vitrification of legacy UMo waste (high-level liquid waste from reprocessed U-Mo-Sn-Al spent fuels) in La Hague cold crucible melter.
Two UMo solutions vitrification campaigns conducted in 2013

GLASS CONTAINMENT FORMULATIONS AND TECHNOLOGICAL QUALIFICATIONS

The CCIM was implemented in the R7 facility for the production of three different types of vitrified waste canisters:

- An intermediate level waste borosilicate glass for the vitrification of corrosive solutions from decommissioning and dismantling of the UP2-400 plant at La Hague. The packages are known as CSD-B canisters.
- A high level waste glass-ceramic for the vitrification of legacy highly-corrosive UMo fission products (from reprocessing U-Mo-Sn-Al spent fuel). The packages are known as CSD-U canisters.
- A high level waste borosilicate glass for the vitrification of UOx fission products (fission product solutions from ongoing LWR reprocessing activities) with a high throughput (the

capacity of the vitrification line is significantly increased (raise of about 30 %) by retrofitting a CCIM). The packages are known as CSD-V canisters.

The features of these three glasses are detailed hereafter.

CSD-B containment matrix

The reference CSD-B glass composition is indicated in Table I.

Table I. CSD-B reference glass composition (wt%)

SiO ₂	48.7
Na ₂ O	12.6
B ₂ O ₃	14.0
Al ₂ O ₃	10.4
RuO ₂	0.1
Ce ₂ O ₃	0.8
SO ₃	0.2
actinides	0.4
Other	12.8

The reference CSD-B glass from the containment glass formulation qualification is a vitreous material fabricated in the region of 1250°C.

The glass frit redox for CSD-B containment matrix was defined to avoid glass foaming phenomena during production at high temperature.

CSD-U containment matrix

The reference UMo glass from the containment glass formulation qualification is a vitreous material fabricated in the region of 1250°C. It is an opaque glass-ceramic. In the molten state the melt is homogeneous, but phase separation and crystallization phenomena occur after cooling in the canister. The glass-ceramic is characterized by secondary phases dispersed in an encapsulating borosilicate glass matrix. The reference UMo glass composition is indicated in Table II.

Table II. UMo reference glass composition (wt%)

SiO ₂	38.7
Na ₂ O	9.4
B ₂ O ₃	13.9
Al ₂ O ₃	7.1
P ₂ O ₅	3.1
MoO ₃	10.0
ZnO	6.0
ZrO ₂	3.3
CaO	6.1
Other	2.4

The maximum range of molybdenum and phosphorus contents in the final glass determines the melting temperature range, which must be higher than the phase separation temperature in order to maintain a homogeneous melt in the crucible. The phase separation temperature depends on the molybdenum and phosphorous concentrations in the glass.

CSD-V containment matrix

The reference “R7T7” UOx glass is loaded with 17.5 wt% of fission products + actinides + noble metals + Zr fines, and with 2.14 wt% of platinoids. The reference UOx glass composition is presented in table III.

Table III. UOx reference glass composition (wt%)

SiO ₂	44.35
Na ₂ O	9.22
B ₂ O ₃	13.34
Al ₂ O ₃	4.18
Fission products + actinides + nobles metals + Zr fines	17.50
Platinoids	2.14

The UOx glass elaborated by CCIM technology exhibits the expected characteristics in terms of homogeneity and platinoids shapes.

Technological and process qualifications

Qualification of the CCIM process, for the three types of glass production, has consisted in different types of full-scale pilot tests with inactive surrogate solutions. These tests, carried out by the LCV’s R&D team at Marcoule in a full-scale pilot of the industrial process including the CCIM, are described below.

- The nominal tests have defined the nominal parameter values which guarantee that the industrial-scale glass has the same characteristics as the laboratory reference glass.
- The sensitivity tests have validated an operating range for operating parameters over the entire composition domain, to maintain the nominal throughput.
- The transient mode tests have defined the operating parameters adjustments necessary to guarantee the chemical composition and microstructure of the final glass and to avoid strong volatility during transient phases.
- The degraded mode tests have defined the operating parameters to preserve the process equipment and the material properties. Means of detection have been determined and management procedures have been defined.
- Finally, the long-term endurance tests have demonstrated that the process is reliable, and that the material properties of the product remain constant over time.

UMo solutions have a strong tendency to stick in the calciner due to the high molybdenum content. D&D solutions also have a strong tendency to stick in the calciner due to the high boron and sodium contents. The calcining parameters (heating power of each zone and rotation speed) have therefore been defined by specific tests without vitrification, and optimized during the qualification process for varying throughputs. The feed solution composition adjustment has also been defined during the inactive qualification. Compliance with calcining and adjustment parameters ensures a proper calcine is obtained and prevents sticking issues.

Qualification of the cold crucible melter for vitrification of UMo solutions also required changes in the process: specific devices, at the outlet of the calciner, were defined and qualified to limit the sticking of molybdenum from calcining exhaust stream in off-gas treatment equipment.

The cold crucible melter control modes were defined by the LCV process licensor. They are specified in the process data book, which includes three levels of information, in accordance with the scope of LCV responsibilities:

- The requirements of the LCV process licensor.
- The operating recommendations based on LCV experience and on the limits of the test program.
- The lessons learned from operating experience.

Another full-scale pilot of the CCIM is installed in AREVA's Beaumont testing and development laboratory. This pilot has no calciner and is specifically devoted to technological development for the CCIM nuclearization and defining some additional operating parameters and procedures for application to the industrial facility. This pilot is operated by AREVA E&P (former SGN) teams.

FEEDBACK FROM THE FIRST FOUR YEARS OF OPERATION

Specific Organization and Methodology for the first CSD-B and CSD-U campaigns

A specific organization was set up for the first D&D effluents vitrification (CSD-B) campaign and the first UMo solution vitrification (CSD-U) campaign, with the following participants:

- The industrial operator of the vitrification units: AREVA NC.
- The Joint Vitrification Laboratory (LCV) as process licensor.
- AREVA E&P (Engineering & Projects).

The feedback obtained with the two inactive prototypes (at Marcoule and Beaumont) was used to verify that the operation of the equipment, during the "witness" runs, was consistent with the inactive tests.

During these campaigns, the operating parameters were monitored by support teams from the LCV (R&D) and AREVA E&P (engineering). The operation of the main equipment on the vitrification line was analyzed in real-time and advices and recommendations were provided during the daily debriefing meetings. When necessary, control adjustments were implemented to improve process performance.

Process parameters were monitored and analyzed in the following areas:

- Energy balance; Thermal parameters
- Electrotechnical parameters
- Technological operation of the melter (stirring, bubbling, glass pouring, etc.)
- Calciner operation
- Off-gas treatment process operation
- Material feeds; Material balance.

The organization set up between the industrial operator, the process licensor, and the engineering teams ensured a detailed analysis of process operation with precise diagnostics of process performance. Some process control adjustments were applied during these "witness" runs, they allowed improving performance of the process.

CCIM production at La Hague

The inactive tests of the CCIM implemented in the R7 facility were performed in 2009 and five "inactive" canisters (inactive surrogate glass) were produced from December 14 to December 23, 2009.

The first active D&D effluents vitrification campaign (CSD-B) was conducted from April 16 to April 30, 2010.

The first UMo effluent vitrification campaign (CSD-U) was conducted from January 3 to January 8, 2013.

As of 31/12/2013, seven CCIM vitrification campaigns have been performed. The campaigns conducted are distributed as follows:

- Five D&D effluents vitrification campaigns (decontamination effluents from the La Hague UP2-400 facility D&D operations). These campaigns were conducted in 2010, 2011 and 2012.
- Two UMo solutions vitrification campaigns (high-level liquid waste from reprocessed U-Mo-Sn-Al spent fuels). These campaigns were conducted in 2013

As of 31/12/2013, 225 canisters were produced from the R7 CCIM. The distribution is as follows:

- 190 CSD-B (glass from decontamination effluents).
- 35 CSD-U (glass from UMo legacy waste).

The next stage of the CCIM deployment in the R7 facility is the vitrification of High-level fission product coming from ongoing reprocessing activities (reprocessed Uranium Oxide fuels).

Feedback on the performances of the CCIM implemented in R7 facility

The performances of the CCIM can be measured by two items that arise directly from the major advantages of this process:

1. Cooling of the crucible forms a solidified layer of glass that protects the equipment from the corrosive melt. It allows a long lifetime of the melter, and this one doesn't have to be treated as a highly active waste after its use.

The CCIM was inspected after each campaign and observations were always the same:

- The remaining glass after draining pour is easily detachable and does not adhere to the melter structure.
- Inspections of the melter after removal of the remaining glass show that its structure is clean and corrosion-free.

The expected performances of the CCIM, in terms of protection of the equipment, are therefore validated in the industrial scale.

2. The CCIM allows the temperature to be increased; the higher temperature allows a faster calcine digestion by the glass and consequently high throughputs and a continuous feeding (no soaking period before pouring).

Expected throughputs for each campaign were obtained. Continuous feeding was operated from the first campaign and did not cause any particular difficulties.

Glass melt temperature is therefore an important operating parameter and its control a key component for glass quality and production throughput. Different optimizations have therefore been implemented to make this functional unit more reliable.

Improvements implemented

Different optimizations have been deployed on the CCIM since its industrial commissioning. These optimizations are technological evolutions of the process in adequacy with its maturity. These improvements are mainly related to compliance with high glass throughputs and decrease of downtime arising from maintenance operations. They are detailed hereafter.

Temperature sensors

The CCIM allows the temperature to be increased compared with the other vitrification processes. This makes it possible to obtain new waste containment matrices which would have been impossible to produce with others vitrification process. Glass melt temperature is therefore an important operating parameter and its control a key component for glass quality (in terms of long term behavior) and production throughput.

Temperature measurement in the cold crucible is performed by two cooled rods immersed in the melt. This technology was developed by the LCV in collaboration with AREVA engineering teams and is subject to protection of intellectual property (patents).

The feedback from R&D on the CCIM temperature specific sensor operating highlighted the need to enhance reliability of this functional unit.

Technological developments have been continuously implemented on this device to enhance its industrial performance. The technological developments have been led by the R&D teams in collaboration with engineering teams. They cover the following items:

- Improvement of mechanical properties of some elements of the equipment.
- Optimization of materials used.
- Optimization of the design of the equipment, especially to improve the cooling.

The long-term operating of these optimized rods, in the inactive prototypes, allowed validating the optimizations implemented and the equipment qualification. Lessons learned from active campaigns in R7 facility with these optimized rods demonstrated a reliability improvement.

The optimizations developed by the R&D teams in collaboration with the engineering teams allowed significantly increasing the lifetime of the cooled rods temperature sensors. Reliability of this equipment is now compatible with long term production vitrification campaigns.

Cross-checking parameters

Temperature of glass melt during operation is one of the parameters ensuring glass quality (glass performance in terms of long-term behavior).

Production of high-quality glass, consistent with requirements of the process licensor, requires the ability to detect potential drift of temperature measurement of the glass melt.

Temperature variation of the glass melt changes its electrical resistivity. The power that the generator must provide is then modified, on the one side to adapt to this new value of resistivity, on the other side to offset new thermal losses due to temperature change.

A drift of the temperature indicated by the control system can be detected by monitoring the following cross-checking parameters:

- Electrical parameters
- Power injected in the glass and thermal losses from the molten glass (thermal power dissipated on each structural component)

Power injected in the glass is the indication of the power necessary for glass synthesis under given conditions. Thermal power dissipated on each structural component is used to estimate the thermal distribution in the melter. Power injected in the glass and thermal losses depend on the load characteristics (mass, temperature, stirring, and composition) and the feed rate.

When stirrer and bubblers parameters, feed rate and glass composition are consistent, power injected in the glass and thermal losses allows cross-checking glass melt temperature information.

The R&D teams, based on their high CCIM operating experience, have developed a methodology for detecting temperature measurement drift by using cross-checking parameters. The deployment of this methodology to the industrial operator was carried out in 2010.

Cross-checking parameters monitoring is now operational and allows operators to readily detect a potential glass melt temperature drift and to take appropriate compensatory measures.

As an example, the graph hereafter shows the evolution of the power injected in the molten glass during a part of the second UMo vitrification campaign. Analysing the injected power showed good stability of the energy balance, reflecting the absence of glass melt temperature drift during the campaign.

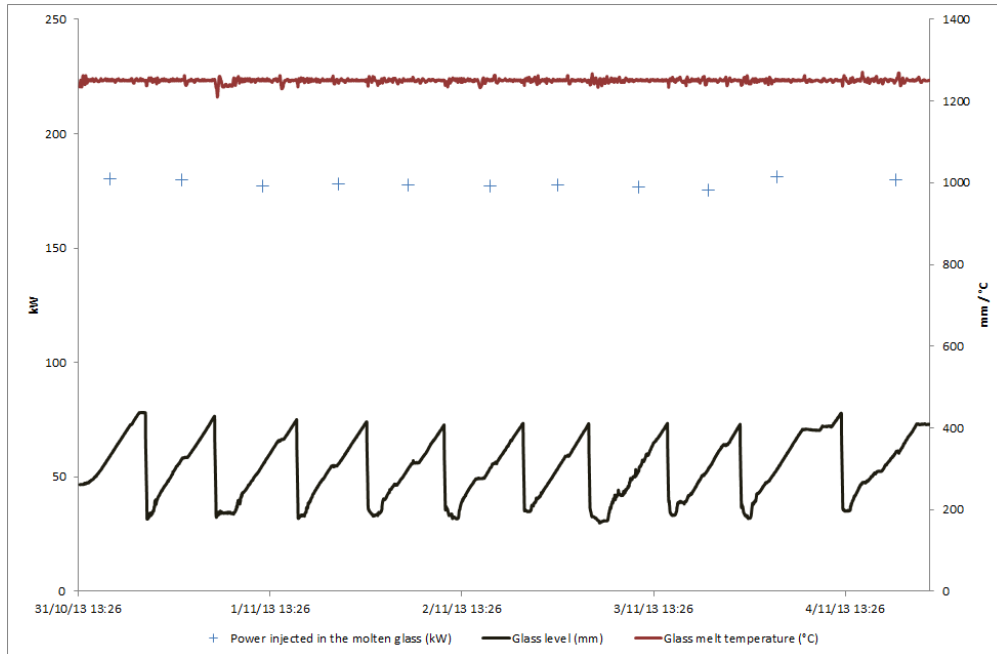


Fig. 4. Power injected in the glass for each batch.

Start-up Phase

Glass has the property of being an electrical insulator when cold and becomes electrically conductive when melted. It is therefore necessary to implement a specific preheating phase of the glass that allows induction phenomenon in the glass to occur.

For each new matrix processed in the CCIM, the start-up procedure had to be adapted to the electrical, chemical, and thermal characteristics of the glass frit.

Different optimisations of the start-up phase were carried out by the R&D teams in order to improve its performance. The start-ups of the last campaigns have allowed confirming the adequacy of procedure that had been defined on the inactive prototypes. The data acquired during the start-up phase of the active campaigns were consistent with the results of the inactive tests and validated the control mode.

Bubblers

Bubblers are important devices of the CCIM, in particular they contribute to the proper reactivity of the glass (proper digestion of cold products arriving on the surface of the molten glass). The feedback on the different R&D tests carried out on the inactive prototypes have highlighted that a degradation of the bubblers, in the first design developed, could occur for certain operating modes.

A phase of R&D aimed at increasing lifetime of bubblers was deployed over the period 2013 – 2014. This phase of R&D led to the deployment of different optimizations of the bubblers. These optimizations were validated and qualified on the R&D prototypes and then deployed on the industrial CCIM in R7 on 2014.

Industrial CCIM in R7 facility is now equipped with the latest design of bubblers. Their lifetime was significantly increased and is now in accordance with the life time of an industrial CCIM.

Operating an efficient and sustainable bubbling in corrosive glasses, at very high temperature is a challenge that was met by the R&D and engineering teams. These optimizations allowed increasing the reliability of the cold crucible and limiting the downtime arising from maintenance operations.

Maintenance operations

The CCIM has been developed with a modular and removable design. In this way, majority of the devices of the CCIM are remotely-removable and can be separately replaced (dome, measuring rods, bubblers, pouring valve, stirrer, ...).

The stirrer was in particular designed in order to be dismantled in hot cell and thus to be able to replace some mechanical parts of the equipment if necessary. In 2013, a replacement operation of a bearing was programmed and successfully performed. This operation is a major demonstration of the high level of maintainability of the CCIM.

The removal design augmented by the high knowledge and experience of the operators allows some high level maintenance operations and thus to increase efficiency of the equipment.

It should also be noted that the low level of contamination of the CCIM, due to the solid glass layer which protects the surface of the melter, allows the operators to carry out hands-on maintenance operations for certain devices of the CCIM. The reason is that the glass does not adhere to the melter structures thereby significantly reducing the final CCIM level of contamination once the solid glass layer is removed prior to maintenance hands-on tasks.

UMo campaigns feedback focus [2]

250 cubic meters of legacy solutions resulting from reprocessing U-Mo-Sn-Al spent fuel in the former UP2-400 plant were produced during the mid-1960s at La Hague facility. These solutions are less radioactive than the current fission product concentrates coming from ongoing reprocessing activities, but are very rich in molybdenum. The high molybdenum content makes the waste very corrosive and also requires a special high-temperature glass formulation to obtain sufficiently high waste loading factors (12% in molybdenum oxide). As standard vitrification technologies are incompatible with the specific features of UMo waste, AREVA is using the CCIM technology to condition it.

UMo solutions are very hard to process because of the high molybdenum content. The main characteristics of the waste behavior in the process are detailed below.

- The waste is very corrosive.
- The solutions have a strong tendency to stick in the calciner.
- Vitrification and calcining exhaust stream may cause strong clogging issues in off-gas treatment equipment.

Two campaigns of UMo waste vitrification in CCIM were carried out in the R7 facility in 2013 for a production of 35 CSD-U canisters.

Special attention was given to the CCIM integrity after the campaigns owing to the very corrosive characteristic of the UMo glass. Special attention was also given to calciner and off-gas treatment operation according to the sticking and clogging issues in these parts of the process.

Analysis of the process parameters showed satisfactory overall operation of the CCIM during these two campaigns. Analysis of cross-checking parameters (energy balance) revealed no process drift. The electrotechnical parameters obtained during the campaign were stable and comparable to those obtained during inactive qualification tests. The electrotechnical operation of the process was satisfactory and corresponded to the expected performance.

The melter operation, during these two first campaigns, was satisfactory and confirmed the results obtained in the R&D and technological facilities. The melter draining pours was performed satisfactorily. The process control parameters applied ensured that the melter was emptied under satisfactory conditions. The residual amount of glass remaining in the melter is low, it corresponds to the glass skull present during its operation and to a small fraction of the melt that remained in the

crucible after it was emptied. The remaining glass was easily detachable, and did not adhere to the melter structures. Inspections of the melter after removal of the remaining glass showed that its structure was clean and corrosion-free.

Compliance with the parameters of UMo solution adjustment and calcining produced a satisfactory calcine and prevented clogging of the tube. Analysis of the calciner process parameters revealed satisfactory calciner operation and validated the qualification obtained under inactive conditions. The interior of the calciner was inspected after the campaigns and the tube was found to be clean, confirming that no clogging occurred in operation (figure 5).

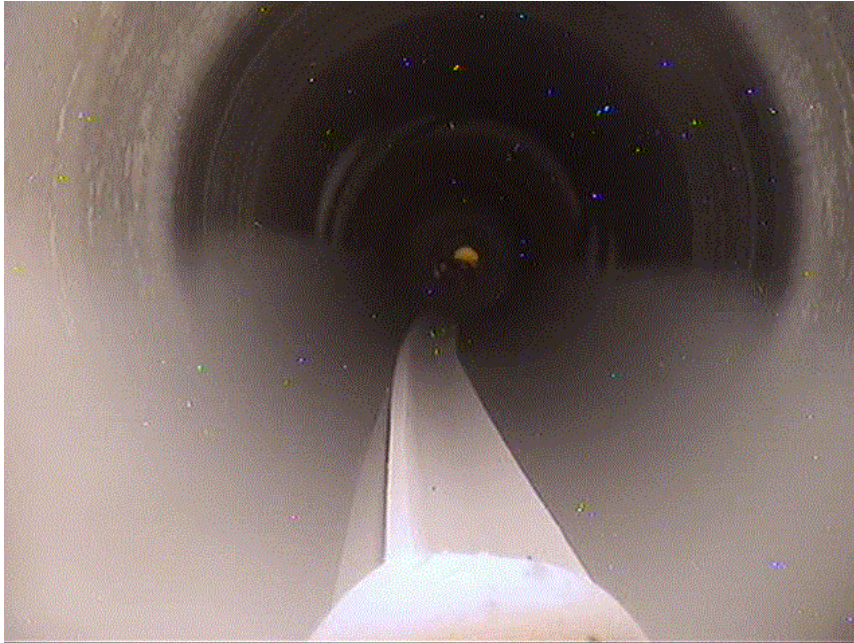


Fig. 5. Interior of the calciner after the first UMo campaign

The duct from the calciner to the scrubber can be critical with respect to clogging by molybdenum compounds. The implementation of specific devices at the outlet of the calciner and the recommendations defined by the LCV and applied by the operators ensured satisfactory operation and allowed reducing the downtime arising from clogging. During these campaigns, the off-gas treatment operation was satisfactory, remained stable and corresponded to the expected performance. The downtime arising from clogging issues is low.

The organization set up between the industrial operator, the process licensor, and the engineering teams ensured a detailed analysis of process operation. Some process control adjustments were applied and allowed improving the performance of the process.

The feasibility of vitrifying UMo fission product solutions in a cold crucible melter at industrial scale has been demonstrated. The operation of the vitrification line was satisfactory and confirmed the results obtained in the R&D and technological development facilities. Vitrifying UMo fission product solutions in a cold crucible melter is a world premiere, it was the outcome of more than 20 years of R&D and close collaboration between R&D, engineering teams and the industrial operator.

CONCLUSION

The Cold Crucible Induction Melter (CCIM) started hot operation in April 2010 for the first time ever in an existing very high active facility (R7) at La Hague. As of 31/12/2013, seven CCIM vitrification campaigns have been performed (Five D&D effluents vitrification campaigns and two UMo solutions vitrification campaigns) and 225 canisters were produced.

The CCIM was inspected after each campaign and the remaining glass after draining pour is easily detachable and does not adhere to the melter structure. Inspections of the melter after removal of the

remaining glass show that its structure is clean and corrosion-free. The expected performances of the CCIM, in terms of protection of the equipment by the solidified layer of glass, are therefore validated in the industrial scale.

Expected throughputs for each campaign were obtained and continuous feeding was operated from the first campaign without any particular difficulties.

Glass melt temperature is an important operating parameter and its control a key component for glass quality (in terms of long term behavior) and production throughput. Different optimizations have therefore been implemented since the beginning to make this functional unit more reliable. Reliability of this functional unit is now compatible with long term production vitrification campaigns.

The R&D teams, based on their high CCIM operating experience, have developed a methodology for detecting temperature measurement drift by using cross-checking parameters. The deployment of this methodology to the industrial operator was carried out in 2010.

Different optimizations defined by the R&D and engineering team have been implemented on the bubblers. Their lifetime was significantly increased and is now in accordance with the life time of an industrial CCIM. These optimizations allowed increasing the reliability of the cold crucible and limiting the downtime arising from maintenance operations.

The modular and removal design of the CCIM augmented by the high knowledge and experience of the operators allows some high level maintenance operations and thus to increase efficiency of the equipment. Major demonstrations of the high level of maintainability of the CCIM have been performed.

The feasibility of vitrifying highly corrosive UMo fission product solutions in a cold crucible melter at industrial scale has been demonstrated. The operation of the vitrification line was satisfactory and confirmed the results obtained in the R&D and technological development facilities.

The industrial operation of the CCIM is the outcome of more than 20 years of R&D and close collaboration between R&D, engineering teams and the industrial operator.

The next stage of the CCIM deployment in the R7 facility is the vitrification of High-level fission product coming from ongoing reprocessing activities (reprocessed Uranium Oxide fuels).

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